THE ROYAL AERONAUTICAL SOCIETY WAS FOUNDED IN 1866

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The Journal of The Royal Aeronautical Society

With which is incorporated The Institution of Aeronautical Engineers

Edited for the Council by Capt. J. LAURENCE PRITCHARD, Hon. Fellow

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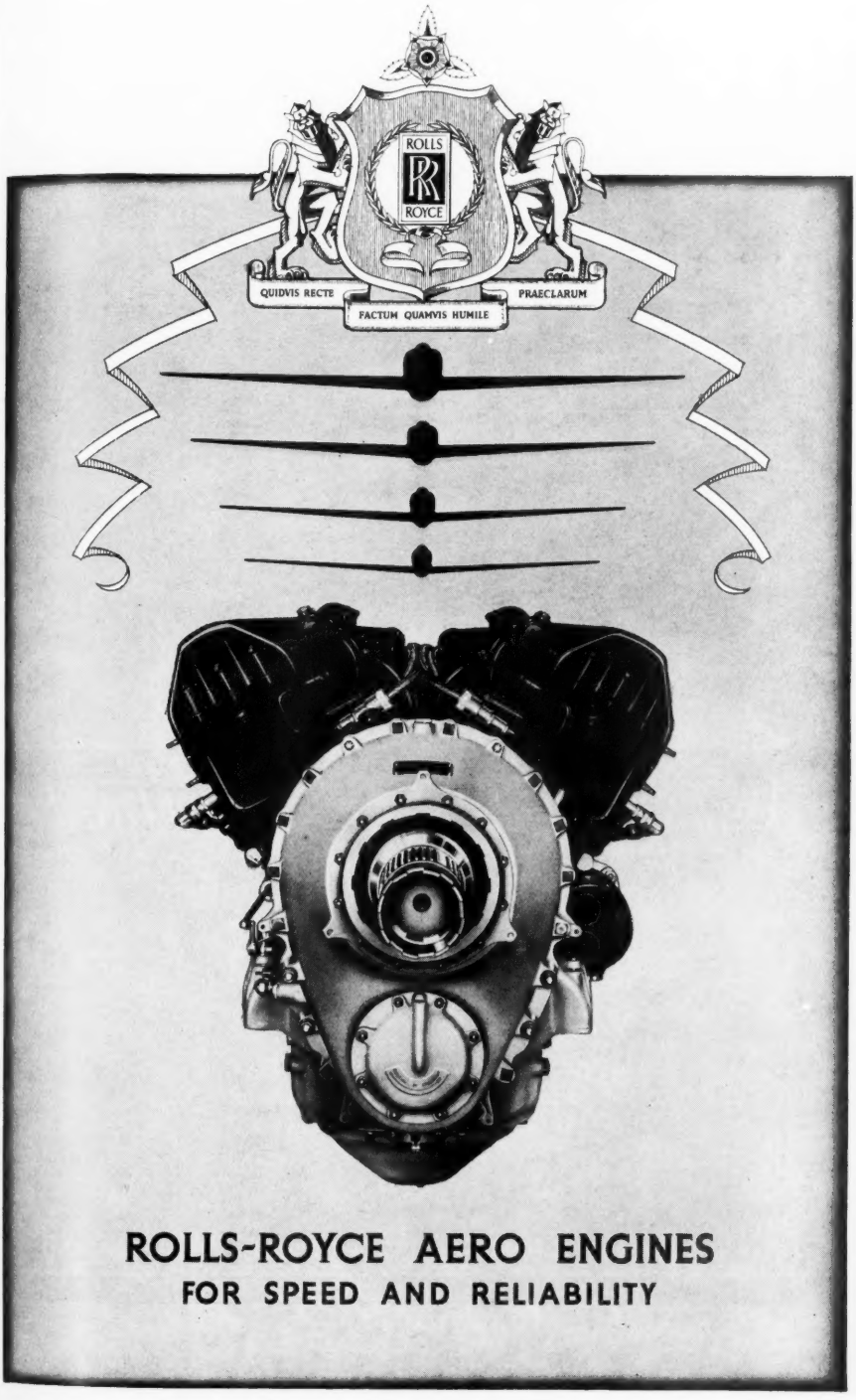

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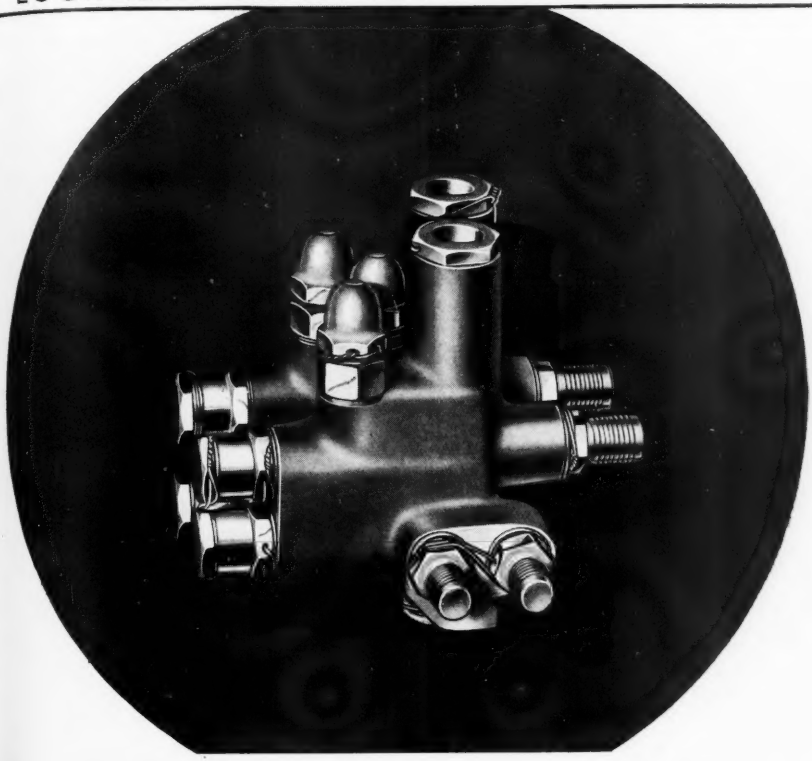

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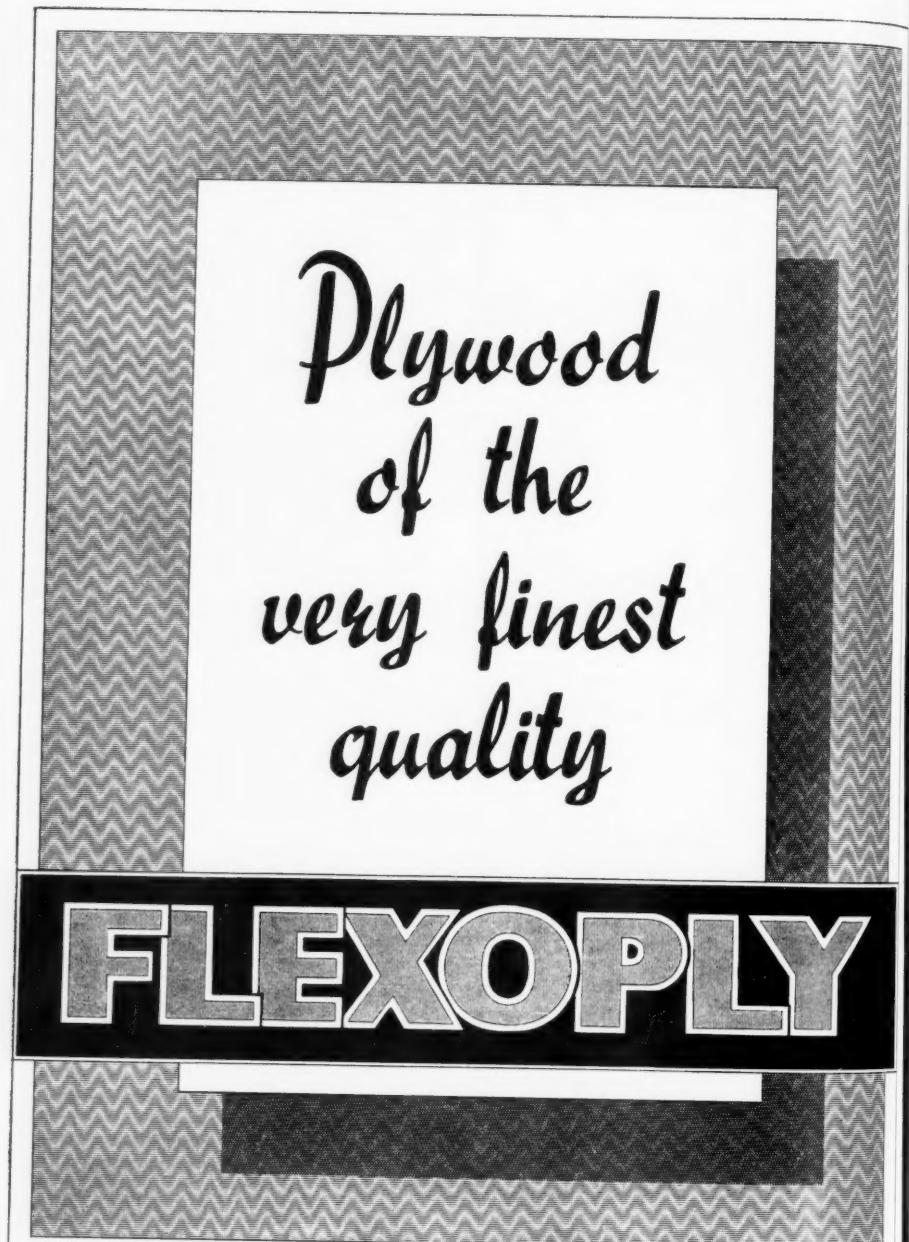
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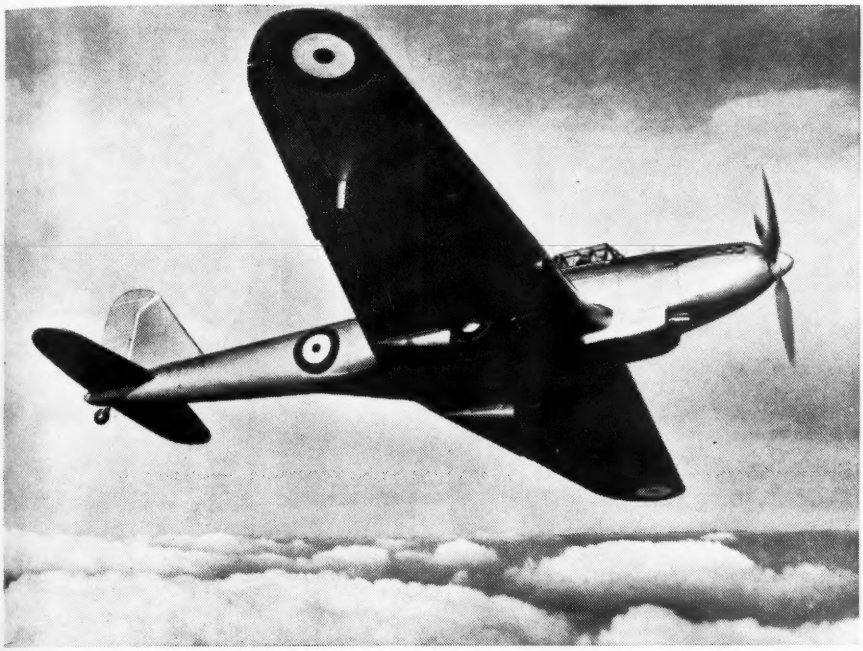

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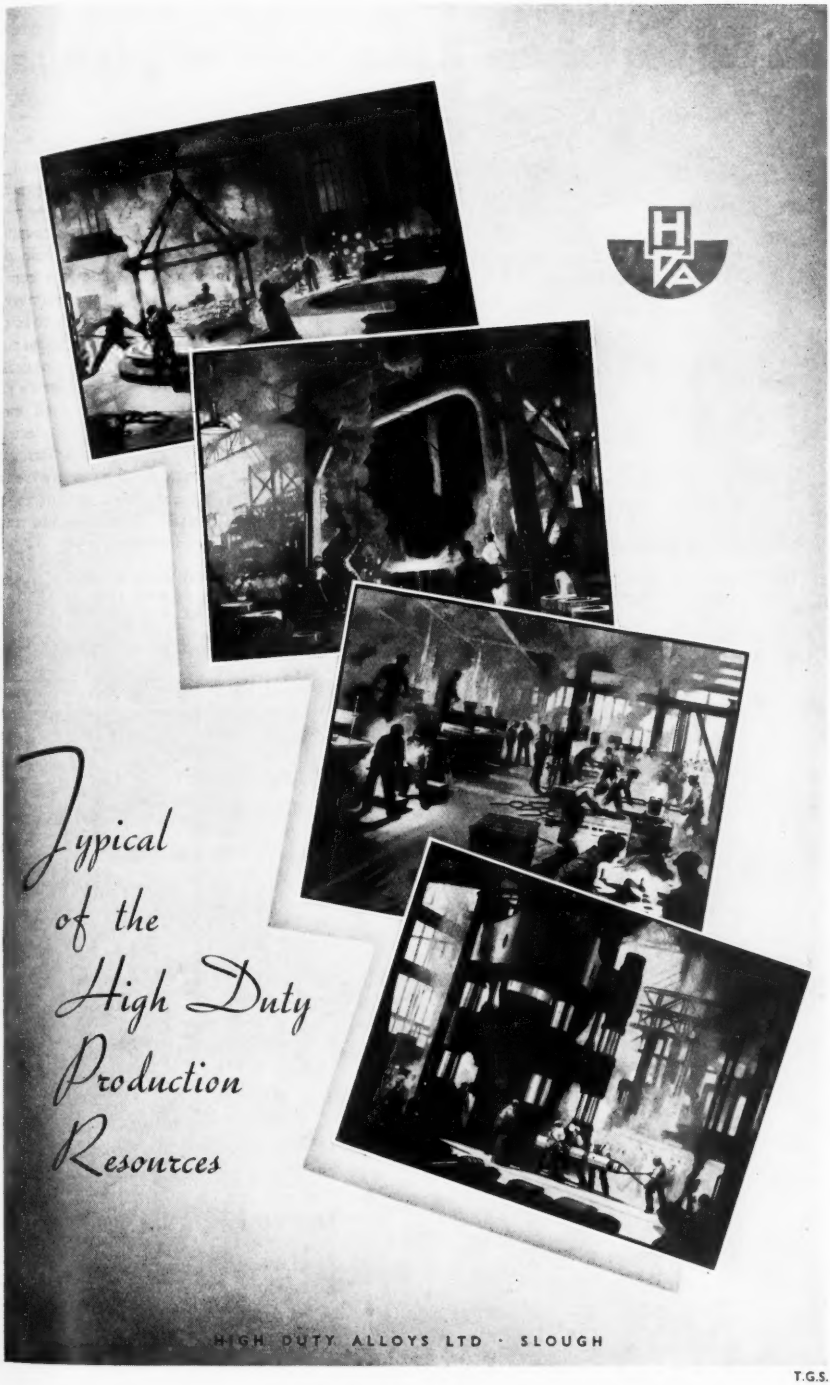
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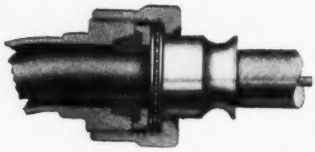

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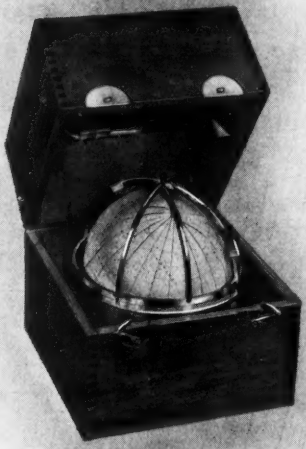

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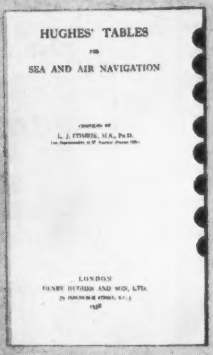

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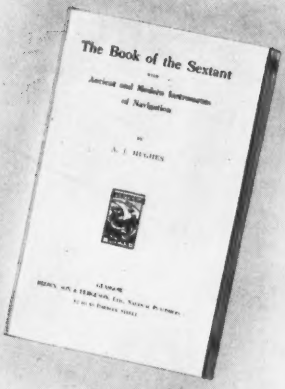

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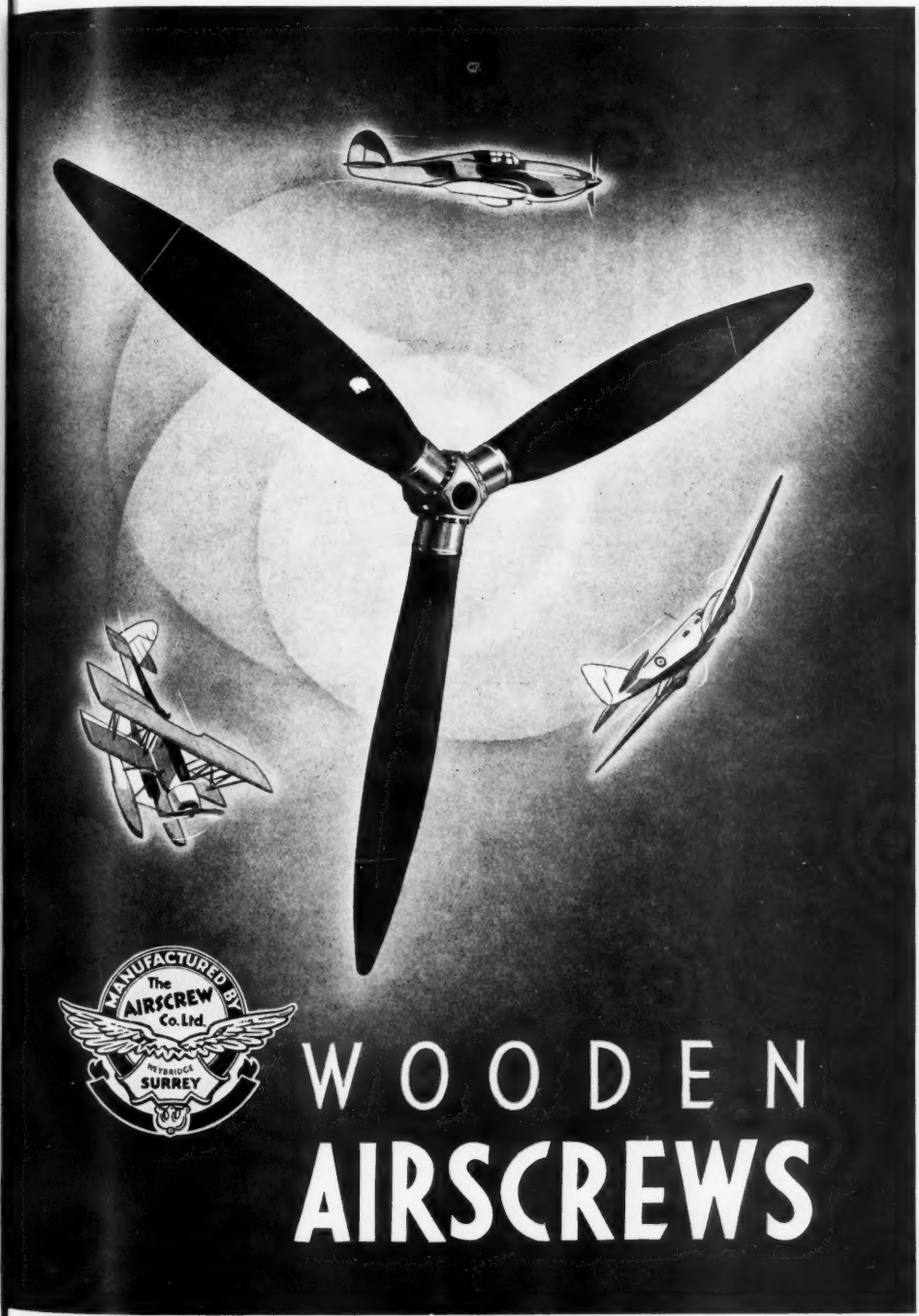
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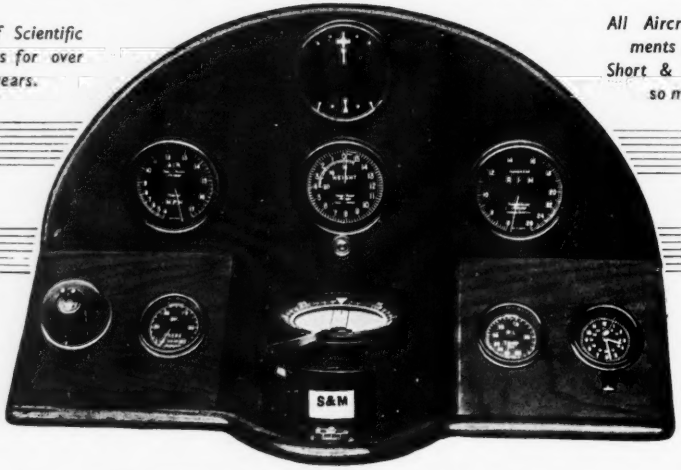

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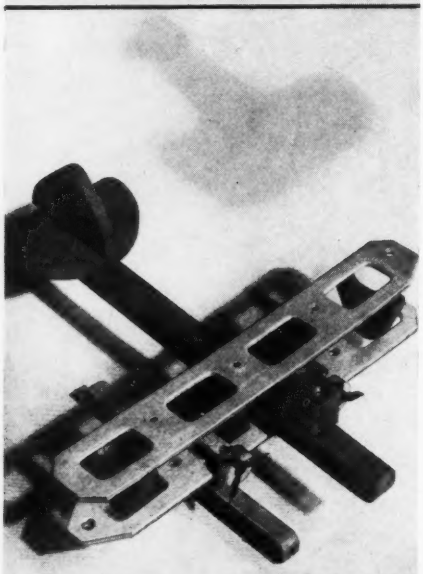

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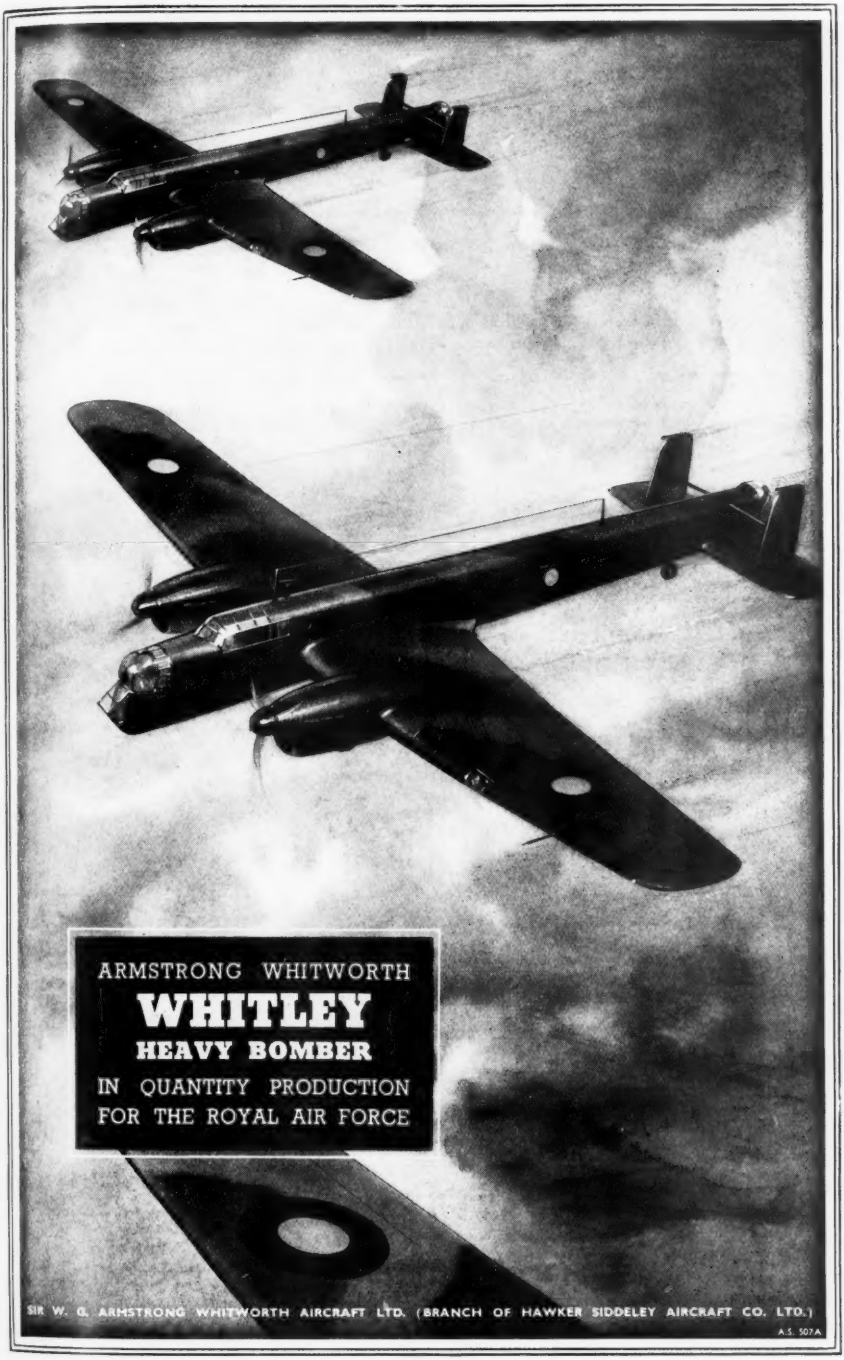
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THE JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY *was founded in* 1897 *in succession to the* ANNUAL REPORTS.

For the opinions expressed in Papers that are signed or initialled the authors alone are responsible. None of the Papers or paragraphs must be taken as expressing the opinion of the Council of the Royal Aeronautical Society, unless such is definitely stated to be the case.

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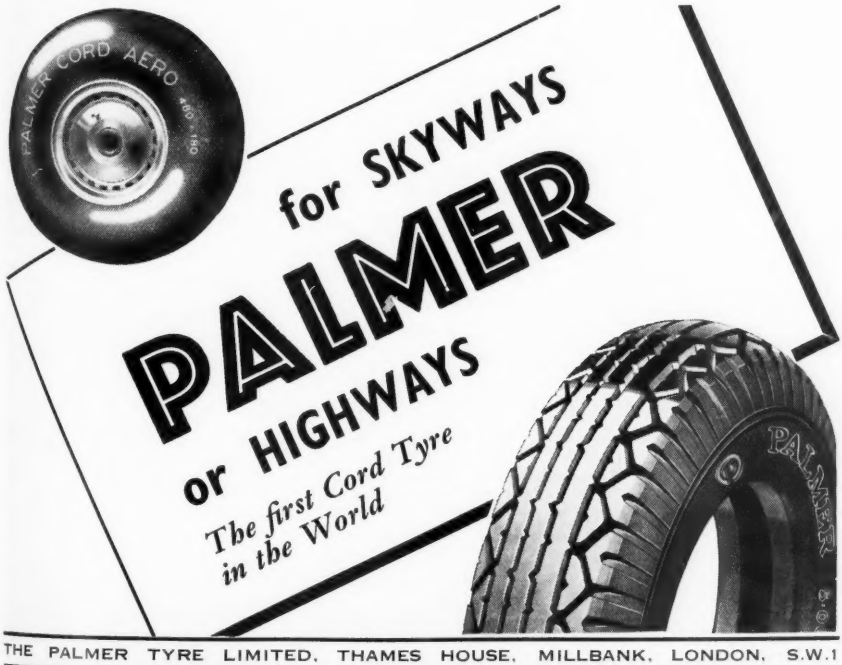

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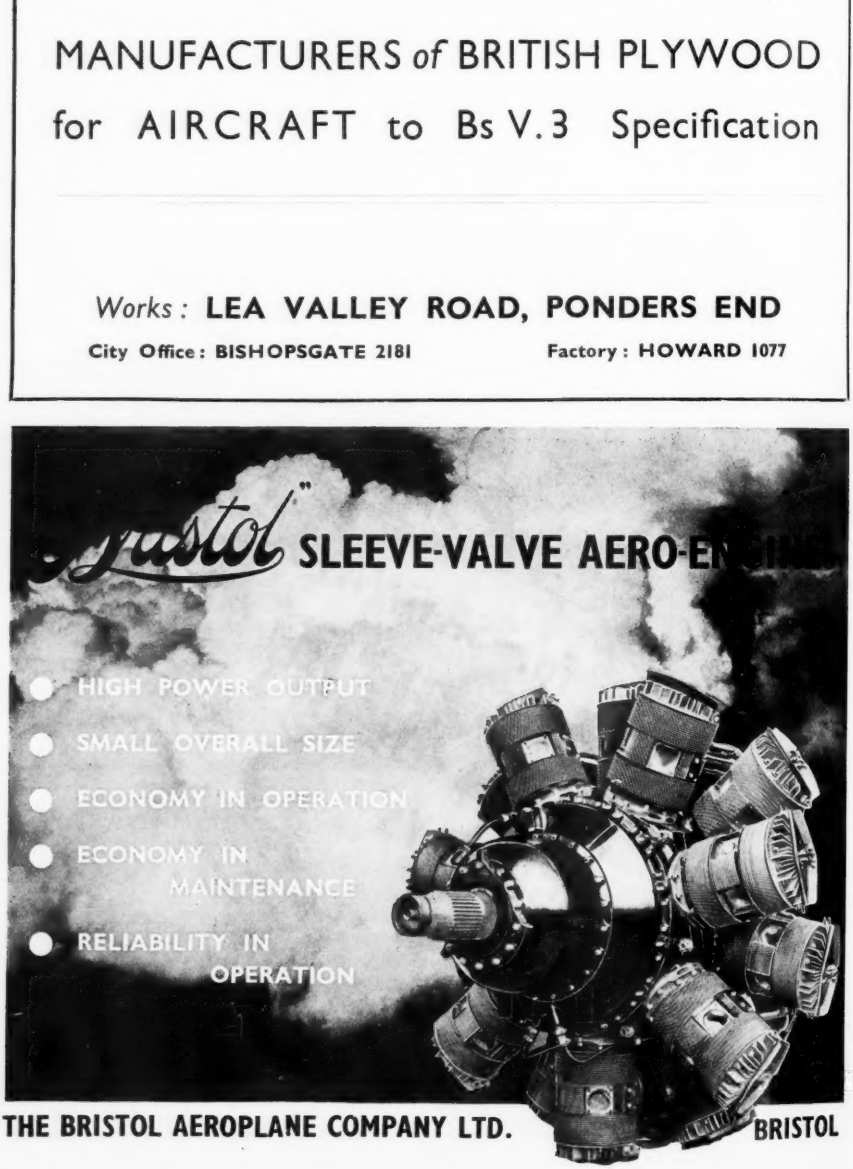

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MONTHLY NOTICES,

MARCH, 1940.

Easter Holidays.

The Library and Offices of the Society will be closed on Friday, March 22nd, 1940, and will re-open on Tuesday, March 26th.

Annual General Meeting.

The Annual General Meeting of the Society will be held in the Offices of the Society at 4, Hamilton Place, London, W.1, at 3 p.m., on Saturday, March 30th, 1940. An Agenda will be sent to all voting members.

Lectures.

Although a number of lectures have been arranged, the attention of members is drawn to the fact that the manuscript of these lectures has to be submitted to the censorship. On that account it may not always be possible to arrange for advance proofs, and in cases of severe cutting down of the lecture by the Censor the Council will reserve the power to cancel the lecture at short notice. Where time permits, any such cancellation notice will be published in *The Aeroplane* and *Flight* and the Journal.

Special General Meeting.

A Special General Meeting, under the chairmanship of the President, Mr. A. H. R. Fedden, was held under Rule 108 of the Royal Aeronautical Society with which is incorporated the Institution of Aeronautical Engineers, on January 27th, 1940, at which 17 voting members were present. The President explained that 20 were required for a quorum and that the meeting could only express its opinion on the proposed change of rules. He read letters from Lieut.-Colonel J. T. C. Moore-Brabazon, Member of Council and at one time President of the Institution of Aeronautical Engineers; from Mr. Handley Page; Mr. C. R. Fairey, President of the Society 1930-1934; Lord Sempill, President of the Society 1927-1930; Mr. W. C. Devereux, Member of Council; Mr. A. Gouge, Member of Council; and Captain P. D. Acland, Member of Council, expressing their full agreement with the proposed changes. The members who met on January 27th, 1940, unanimously agreed that the changes in the rules were in the best interests of the Society.

Under Rule 110 the postponed Special General Meeting was held on Saturday, February 10th, under the chairmanship of Mr. S. Camm, Member of Council, and at this meeting the proposed changes in the rules were unanimously agreed to.

The changes in the rules followed resolutions to the Council and which were passed at the Annual General Meeting in March, 1939. In the Journals of March, April, May, July, August and September, 1939, the attention of members was drawn to the resolutions and announcements made that the Council had appointed a Rules Committee to consider the resolutions and to submit a report to the Council. The report was ready in September, 1939, and on account of the war the Council's decision on the report was postponed until December, 1939. At the December meeting the Council accepted the report and the Special General Meeting was called.

The main effects of the alterations of the rules are to abolish the grades of Membership and Associate Membership and merge them into those of Fellowship and Associate Fellowship respectively; to allow the admission of members of the Industry who are over 40 years of age, have had 15 years' practical experience in aeronautics; and have had a record of distinguished service, without necessarily having passed the examinations of the Society or exempting examinations. The forms of such candidates must be signed by four full Fellows of the Society. In addition, the qualifications for the Associateship grade have been considerably raised, to raise the status of the grade. Candidates in future, for example, must be at least 25 years of age, instead of 21, hold at least three ground engineer's licences, instead of two, and have at least three years' experience instead of two. Nothing in the alterations affects the present full title, the Royal Aeronautical Society with which is incorporated the Institution of Aeronautical Engineers. This is the full and correct title of the Society and will remain so on all publications, notices, notepaper, diplomas, etc.

Wilbur Wright Memorial Lecture.

The 28th Wilbur Wright Memorial Lecture will be given by Dr. H. Roxbee Cox, D.I.C., B.Sc., F.R.Ae.S., on Thursday, May 30th, at 6.30 p.m., in the Lecture Theatre of the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, W.C.2. The subject of the lecture will be The Future of British Civil Aviation.

Secrecy.

The following letter has been received from the President urging members to exercise care regarding the discussion of matters of a secret nature connected with the work they are doing.

March 18th, 1940.

Dear Sir,

The Royal Aeronautical Society has been asked by the Air Ministry to draw the attention of all its members to the vital importance of secrecy during the war. In particular, it has been requested to bring to the attention of all grades of members that it is their duty to be most careful not to divulge any figures regarding the production of the firm with which they are connected, not to discuss in front of anyone, the production or possible production, of other firms.

We therefore ask the earnest co-operation of all members, whether in the industry or not, to ensure secrecy in this respect.

Thanking you for your help,

Yours faithfully,
(Signed) A. H. R. FEDDEN,
President.

Members' Subscriptions.

Members are reminded that their subscriptions were due on January 1st, 1940. The Council hope that every member will make every effort to pay his subscription as early as possible. The rates are:—

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Acknowledgment.

The Council acknowledge with grateful thanks the gift of books and pamphlets from Mr. A. R. Weyl, Associate Fellow; the gift of a fine collection of lantern slides from Messrs. Rotax, Limited; and a donation to the Endowment Fund of 7s. from Mr. J. V. Saunders, Associate Fellow.

Society's Examination Results.

The following candidates were successful in the December, 1930, examinations:

J. W. A. Andrews	Design (Aero Engines). Theory of Internal Combustion Engines. Applied Mathematics.
R. Clemens	Applied Mathematics.
H. F. O. Dawes	Strength of Aeronautical Materials and Structures. Aircraft Materials (First Place).
R. B. Dickenson	Design (Aero Engines). Theory of Internal Combustion Engines. Applied Mathematics.
H. Donovan	Aircraft Instruments (First Place). Aerodynamics (First Place).
N. F. Downes	Strength of Aeronautical Materials and Structures.
E. G. Dunsford	Aircraft Instruments. Theory of Machines.
B. St. John Emery	Design (Aero Engines). Theory of Internal Combustion Engines (First Place). Applied Mathematics.
N. Geen	Design (Aero Engines). Theory of Internal Combustion Engines. Applied Mathematics.
L. S. Greenland	Applied Mathematics.
H. M. Hackett	Design (Aero Engines). Theory of Internal Combustion Engines. Applied Mathematics.
R. W. J. Horsley	Theory of Internal Combustion Engines. Design (Aircraft).
A. G. Kemp	Aircraft Instruments.
D. M. McElhinney	Design (Aircraft). Pure Mathematics.
P. McGinn	Theory of Internal Combustion Engines.
C. F. Onions	Design (Aero Engines) (First Place). Theory of Internal Combustion Engines. Pure Mathematics.
T. B. O'Reilly	Strength of Aeronautical Materials and Structures.
W. H. Paine	Strength of Aeronautical Materials and Structures. Aerodynamics. Pure Mathematics.
E. C. W. Pearce	Design (Aero Engines). Theory of Internal Combustion Engines. Applied Mathematics.

J. A. Ross	Design (Aero Engines). Applied Mathematics.
F. E. Sahyoun	Theory of Internal Combustion Engines
F. Shroff	Design (Aero Engines). Theory of Internal Combustion Engines. Applied Mathematics.
J. A. Tickner	Design (Aero Engines).
D. I. Vickery	Strength of Aeronautical Materials and Structures (First Place). Design (Aircraft) (First Place). Pure Mathematics (First Place).
F. V. Walker	Aircraft Materials.
E. J. Weiss	Design (Aircraft).
J. A. Withnell	Design (Aero Engines). Theory of Internal Combustion Engines. Applied Mathematics.

Election of Members.

The following members were recently elected:—

Fellows.—Francis Percy Hyde Beadle (from Associate Fellow), William Herbert Hatfield (from Associate Fellow).

Associate Fellows.—Alfred Herbert Aylwin Bastable (from Graduate), John William Thomas Brackett (from Student), Frederick George Ronald Cook (from Student), Thomas Fairley, Ronald Walter Frank Farthing (from Student), Reginald George Robert Goldby, Clifford Douglas Graham (from Student), Ruben Hadekel (from Graduate), Benjamin Hodkinson, Frederick S. Mitman, Morien Bedford Morgan (from Student), Alfred Alan Morton, Stanley Alderson Powell-Jones (from Student), George Allan Spiers, Lokusatu Heva Sumanadasa (from Graduate), Cedric Ormonde Vernon (from Student).

Associates.—Harold James Field, David Gilbert (from Student), Jack Haworth, Frank Hopes, Arthur Longden, Selwyn Cecil Perry (from Student), Peter Alfred Henry Pooley (from Student), William Herbert Rowden, Jack Percival Thompson (from Student), Stanley Francis Titt (from Student), Wilfred Bert Watts, John Yeadon.

Graduates.—Maurice Lawson Hall, Vernon Arthur Moore Hunt (from Student), Joseph Kelvin Keelaghan (from Student), Edward James Lane, Reginald Douglas Mogford.

Students.—Edward John Nicholas Archbold, Werner Heinz Harald Axelrad, Leo Batenburg, John Douglas Bennett, James Arthur Clarke, Ernest Jesse Thomas Day, James Alexander Downie, Percy John Duncton, Frederick Charles Emberton, John Shearer Forrester, Lawrence Vincent Gallagher, Hans Frederick Gans, John William Housego, Kenneth Lionel Jordan, Peter Gerhardt Kempner, Francis William Morgan, John Mullin, Wilfred Dennis Pereira, Arthur William Pope, Walter Augustus Ernest Puntis, Norman Ring, John Gilbert Russell, Brian John Stedman, Raymond Frederick Thompson, Roy Harold Warr, Robert Herbert Whitby, Harold Robert Wood.

Companions.—Clive Copeman Bull, John Sterndale Scott Cox (from Student), Walter M. Reichsfeld.

Additions to Library.

Ref.

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UU.b. National Advisory Committee for Aeronautics: Reports:—

No. 664. Wind Tunnel Investigation of an N.A.C.A. 23012 Airfoil with Various Arrangements of Slotted Flaps. By C. J. Wenzinger and Thos. A. Harris.

No. 668. Wind Tunnel Investigation of N.A.C.A. 23012, 23021 and 23030 Airfoils with Various Sizes of Split Flap. By C. J. Wenzinger and Thos. A. Harris.

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UH. 3.—Atti di Guidonia. (Editoriale Aeronautica, Rome):—

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WB. 12/18 and 19.—Institution of Electrical Engineers:—
Journal, Vols. 84 and 85 (1939).

Y. 23.—British Standard Specifications:—

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BB.e.16.—Die Junkers Lehrschau. By Dr. H. Koppenberg. Junkers A.G., Dessau. 1936.

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E.f. 55.—JU/52/3m: Betriebs-Anweisung. Junkers A.G., Dessau. 1936.

EE.a. 53.—Care and Maintenance of the 120 h.p. D.H. Gipsy III Aero Engine. De Havilland Co.

EE.a. 54.—Instruction Book for the Armstrong Siddeley Air-Cooled Radial Aero Engines: Genet. Armstrong Siddeley Motors, Ltd. 1930.

EE.a. 55.—Instruction Book for Armstrong Siddeley Radial Aero Engines: " Jaguar " and " Lynx." Armstrong Siddeley Motors, Ltd.

EE.a. 56.—Care and Maintenance of the " Cirrus " Engine. (Mark II.) A.D.C. Aircraft Ltd. 1927.

EE.a. 57.—Features in the Design and Construction of the Bristol "Jupiter" Radial Air-Cooled Aero Engine. Bristol Aeroplane Co.

EE.a. 58.—The Bristol " Lucifer " Series IIIA Engine. Notes on Installation, Running and Maintenance. Bristol Aeroplane Co.

EE.b. 24/Y.7.d.B.—The Bristol " Jupiter " Air-Cooled Aero Engine (Series VI) and its Production. Bristol Aeroplane Co.

EE.c. 35.—The Causes of Detonation in Internal Combustion Engines. By H. T. Tizard. E. F. and N. Spon, London. 1921.

EE.f. 27.—Betriebsanweisung und Wartungsvorschrift für Junkers Schweröl-Flugmotor Jumo 205. Junkers Flugzeug und Motoren-Werke, Dessau. 1938.

G.a. 28.—The Estimation of Cold Work from X-Ray Diffraction Patterns. By Leopold Frommer. High Duty Alloys, Slough. 1939.

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G.b. 22.—Non-Corrodible Aero Steels (including Heat-Resisting Steels): Specification Chart. Firth-Vickers Stainless Steels, Ltd. 1940.

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M.b.28/PM.2.c.5.—Brown's " Vick " Morse Cards. (Set of Cards in Envelope.) Brown, Son and Ferguson. 9d. 1940.

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X.a. 39 and 40.—Junkers Ratgeber. (Instructional Booklet.) Junkers, A.G. Published by C. Dünnhaupt, Dessau. 1936 Ed., R.M. 1.50; 1937 Ed. (unpriced).

Forthcoming Events.

Tuesday, March 12th, at 6 p.m.—Lecture by Mr. H. J. Pollard, F.R.Ae.S., on "Aircraft Production," in the Lecture Hall of the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, W.C.2.

Wednesday, March 20th, at 3 p.m.—Meeting of Council in the Offices of the Society.

Saturday, March 30th, at 3 p.m.—Annual General Meeting in the Offices of the Society.

Coventry Branch.

Tuesday, March 12th.—"Optical Methods of Measuring, as Applied to the Aircraft Industry," by Messrs. Clarke and Hancock.

J. LAURENCE PRITCHARD, *Secretary and Editor.*

The 647th Lecture read before the Royal Aeronautical Society since its foundation on January 12th, 1866.

PROCEEDINGS.

A meeting of the Society was held in the Lecture Hall of the Institution of Mechanical Engineers, at Storey's Gate, Westminster, London, S.W.1, on Thursday, May 4th, 1939, at which a paper on "Stress Analysis of Thin Metal Construction" was presented by Mr. H. L. Cox, M.A.

In the chair, Dr. Roxbee Cox, Fellow of the Society.

The CHAIRMAN: He had had close personal contact with the lecturer for a long period through the Structure Sub-Committee of the Aeronautical Research Committee, of which Sub-Committee the lecturer was Secretary. Since he had left Cambridge University he had been engaged on a variety of work in the Engineering Department of the National Physical Laboratory, and he had also carried out a large amount of valuable work for the Structure Sub-Committee during the past few years.

STRESS ANALYSIS OF THIN METAL CONSTRUCTION.

By H. L. Cox, M.A.

1. INTRODUCTION.

In seeking to analyse the stress distribution in a complex structure, our object is really twofold. In the first place, if the stress in each part is accurately known, the strength of each part separately can be assessed on the basis of tests on simple units and the necessity for testing the complete structure may be avoided. In the second place, if the stress distribution can be expressed as a function of the geometry of the structure, the effect of varying that geometry, particularly with the object of realising Holmes' one-hoss-shay, can be examined theoretically and arbitrary features of the design can be eliminated. If our knowledge were complete, any structure designed to a maximal or minimal condition would not permit any variation from one ideal form, the design would be uniquely determined by the stated requirements.

The ultimate object of stress analysis must always be so to improve our knowledge that all arbitrary features of design may be eliminated. I emphasise this point at the beginning, because although all of us apply this inevitable procedure of design in matters of detail, as for instance in the design of a tie bar, in more complex problems the desirability of being able to apply the same method is often ignored. Much of this lecture will be devoted mainly to the test aspect of stress analysis, but the design aspect will always be there in the background and will stand as justification for methods of analysis which might otherwise be considered unnecessarily complicated or even academic. In both its aspects stress analysis depends in the end on the results of actual tests; but the more highly developed the analysis, the less complicated need be the test. We can always find out what load any structure will carry by testing it as a whole; but alternatively we may be able by analysis of the stress distribution to determine the part most likely to fail, and then we need test that part only. In this way quite simple and inaccurate stress analysis can be supplemented by tests so designed in relation to the parent structure that the errors in the method of stress analysis are largely eliminated, though naturally greater accuracy will always be obtained by more detailed stress analysis. The golden rule is always to include in the

test specimen all those parts for which stress analysis has not been attempted. I shall try to illustrate this point in a moment in discussion of the tests on tubes and quadrants carried out by the R.A.E. (4).

2. Buckling of Panels.

In discussing the stress analysis of thin walled structures we have to take into account the effect of different types of buckling which may occur successively as the load is increased. The effect of buckling is always to cause a more or less uniform stress distribution in the structure to become less uniform, with the result that the actual maximum stress after buckling is always greater than the apparent stress.

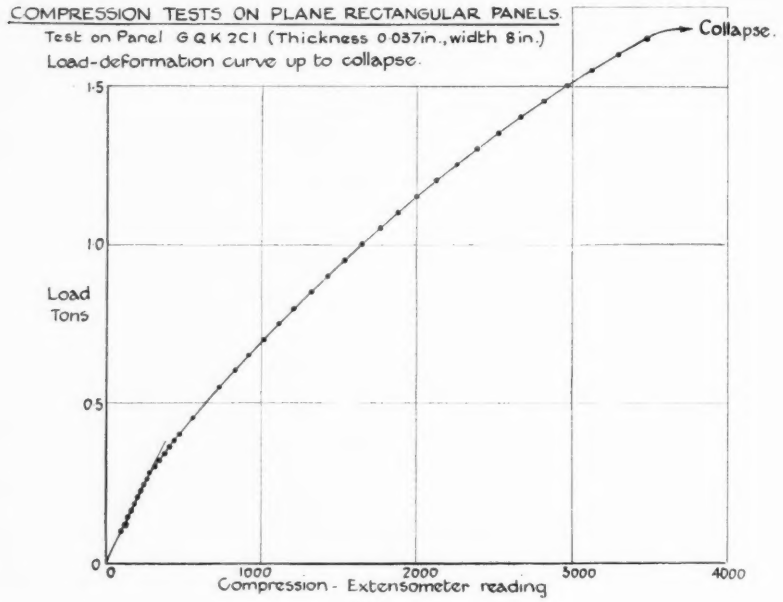


Fig. 1.

Experimental curve for flat panel.

(*a*) *Flat Panels.*—Thus in the case of the flat panel with its edges supported or clamped, the effect of buckling of the centre of the panel is partially to relieve that portion of load whilst the edges still must support the full stress corresponding to the strain (18). As a result the experimental stress-strain curve takes the form shown in Fig. 1. Up to the buckling load the panel remains flat and the stress is uniform. After buckling, the mean or apparent stress still increases with the strain or edge stress, but at a greatly reduced rate. The theory of the buckling of flat panels and of the behaviour after buckling is well established (10-14), and as will be seen from Fig. 2, experimental results confirm the theoretical behaviour quite reasonably well; but there is still considerable divergence of practice as to the manner in which the data should be used. The Americans in particular have generally adopted the conception of equivalent width (19). Fig. 3 shows the theoretical stress-strain curve for a panel with clamped edges; the ordinates may be taken as values of apparent or mean stress (load/area) and the abscissæ as values of actual edge stress (strain × modulus).

The ratio of the effective width to the actual width at any load is the slope of the chord from the origin to that point. Clearly this slope varies with the load, so that the effective width cannot be stated unless the load or edge stress is known. For this reason, I prefer a different method of depicting the behaviour of the panel. It will be seen from Fig. 3 that the relation between apparent and actual stress after buckling is nearly linear, and in general this relation can always be expressed with sufficient accuracy by a straight line. If then we specify the

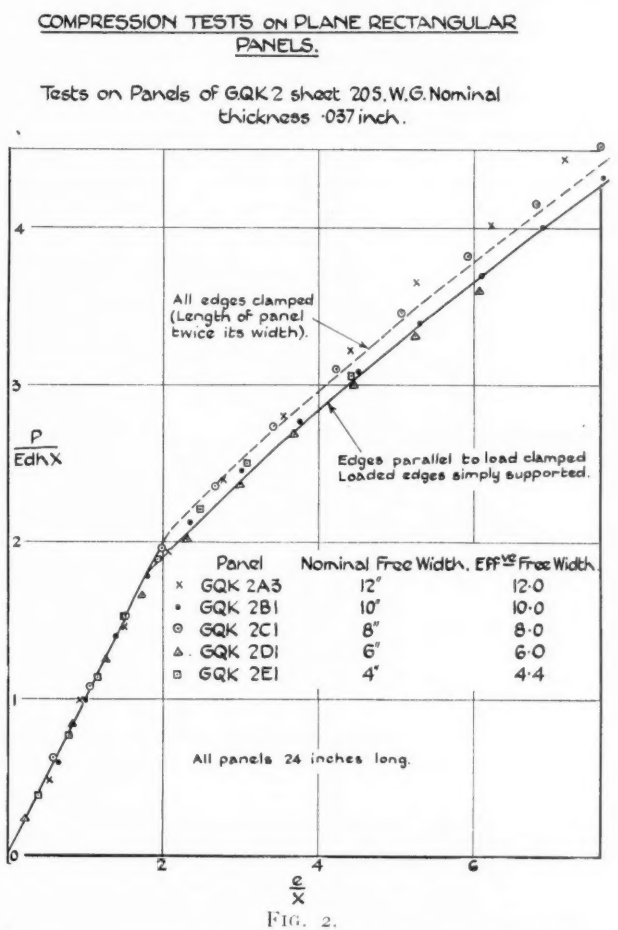

COMPRESSION TESTS ON PLANE RECTANGULAR PANELS.
Tests on Panels of GQK 2 sheet 20 S.W.G. Nominal thickness ·037 inch.
All edges clamped (Length of panel twice its width).
Edges parallel to load clamped Loaded edges simply supported.
P / EdhX
Panel | Nominal Free Width. | Eff^ve Free Width.
× GQK 2A3 | 12" | 12·0
• GQK 2B1 | 10" | 10·0
⊙ GQK 2C1 | 8" | 8·0
△ GQK 2D1 | 6" | 6·0
□ GQK 2E1 | 4" | 4·4
All panels 24 inches long.
0
1
2
3
4
2
4
6
e / X

FIG. 2.

Theoretical curve for flat panels with experimental results.

buckling stress f_b and the ratio n of the rate of increase of actual stress to the rate of increase of apparent stress after buckling, we have a complete representation of the behaviour of the panel. Owing to the curvature of the stress-strain diagram after buckling, the most appropriate value of f_b will be slightly greater than the true buckling stress, and the excess of n above the theoretical value of 2 appropriate immediately after buckling will depend to some extent on the maximum value of f_c for which provision is to be made. Later I shall attempt

to show how these data may be used to determine the stress distribution in a tube subjected to bending; but for the moment I wish to remark upon certain pitfalls in the use of the equivalent width method.

(*b*) *Equivalent Width.*—At first sight the conception of an equivalent width of panel acting with each stringer appears to offer a valuable simplification in that these composite units may apparently be treated as if they acted individually, the continuity of the sheet being in fact ignored (56). This method is, however, fundamentally unsound. Firstly, as Hoff (6) has pointed out, in considering buckling of the *stringer* the effective width of the sheet to be associated with the stringer is not the chord value of Fig. 3 but the tangent value—in fact approximately the ratio $1/n$; for flexural rigidity, which determines buckling, depends upon the stiffness to variation of load about the mean load and not upon the mean stiffness over the whole range from zero load. Secondly, by this method the contribution of the panel is the same whatever the section of the stringer, whereas there is no doubt that the behaviour must depend to a considerable extent on the size of the stringer in relation to the panel. For consider

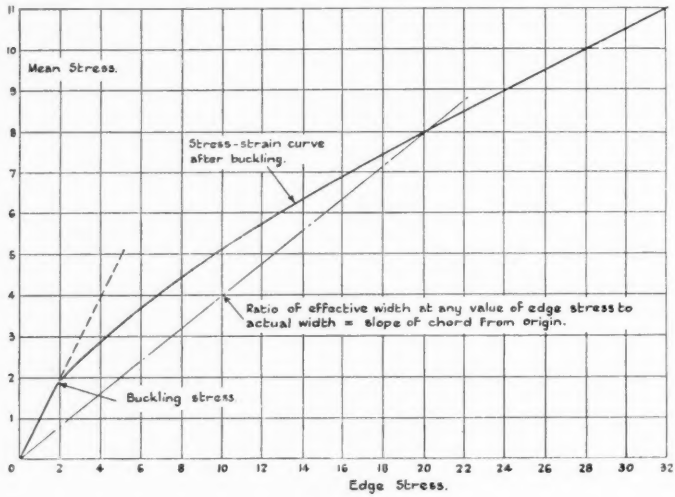


FIG. 3.

Theoretical curve for flat panels showing effective width.

a single stringer riveted down the centre line of a rectangular panel. If the stringer were absent, the panel would buckle with its maximum amplitude on this line. Clearly if the stringer had very little rigidity, this type of buckling might still occur although at a higher stress. If the stringer were relatively stiffer, the side panels might buckle before the central stringer; but only in cases where the central stringer was very stiff indeed, so that the wave form in the side panels was very well developed before the stringer buckled, would the equivalent width method even with Hoff's amendment be likely to afford an accurate result. This argument is only qualitative; but it is sufficient to show the danger of the equivalent width method. I shall discuss this point quantitatively again later.

(*c*) *Curved Panels.*—In the case of curved panels, the few experimental results which have been published (30) do not conform at all well to theory (28). The discrepancies are similar to those characteristic of tests on complete tubes (36), where a far larger number of experimental results is available. The experimental

values of buckling stress vary between wide limits, but the average values are only about half the theoretical values, and the wave form of the buckled sheet differs rather markedly from the theoretical form. Moreover, the experimental behaviour of curved panels exhibits some peculiar features which are illustrated in Fig. 4. Up to the buckling load the panel retains its cylindrical form and the stress is everywhere uniform; but immediately upon buckling, which often occurs with explosive violence, a deep lozenge-shaped inward buckle is formed and the load falls considerably. On unloading, the buckle disappears again quite suddenly and the load *rises* whilst the strain is being reduced. On reloading, buckling again occurs suddenly, but at a much lower load and with a much smaller decrease of load. These effects are most noticeable in cases where the thickness is large in relation to the radius of curvature; but they are nevertheless quite typical. In the case shown in Fig. 4, where the panel was particularly well formed, the actual buckling load was nearly 80 per cent. of the theoretical value.

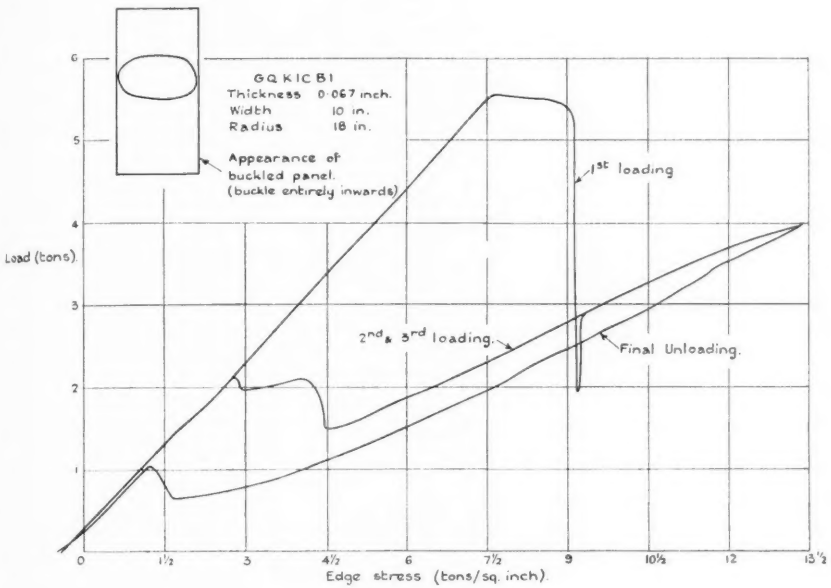


FIG. 4.
Curved panel test result.

The existing theory would not lead one to expect this rather eccentric behaviour of the buckled panel and this behaviour is entirely at variance with the explanation of the low experimental results by which everything is attributed to initial irregularities from the cylindrical form (36). Initial irregularities usually cause the wave form to be developed gradually, so that no definite buckling load is observed. I have felt for some time that initial irregularities could not be the whole explanation; but at the same time I could see no reasonable explanation of diagrams such as Fig. 4. Recently, however, I was led to consider the buckling of a strut, the centre of which is braced by two rods in the plane perpendicular to the strut and including an angle a little less than 180°, the outer ends of the rods being pin-jointed to rigid supports. Clearly if the strut buckles in one half wave, the rods will be either extended or compressed; but if

they are compressed their resistance to further deflection of the strut will be reduced, until when they are brought into line, they will begin to *help* to bow the strut. This system then offered a prospect of a fall of load at buckling and I analysed it in detail. The result, shown in Fig. 5, was even more illuminating than I expected. The curve defining the behaviour after buckling is actually tangential to the elastic line, the upper branch (not shown in Fig. 5) corresponding to tension in the rods, the lower to compression.

Experimental realisation of the theoretical buckling load is, therefore, extremely improbable, for even a minute deviation from straightness of the strut will cause it to buckle inwards prematurely; for the same reason wide variations of test results are to be expected. After buckling the load falls to a value slightly lower than the buckling load of the strut unstiffened, passing through this value on the way down when the rods are in line, and on the way up when the rods are once more unstressed. In any ordinary test this second position or a position

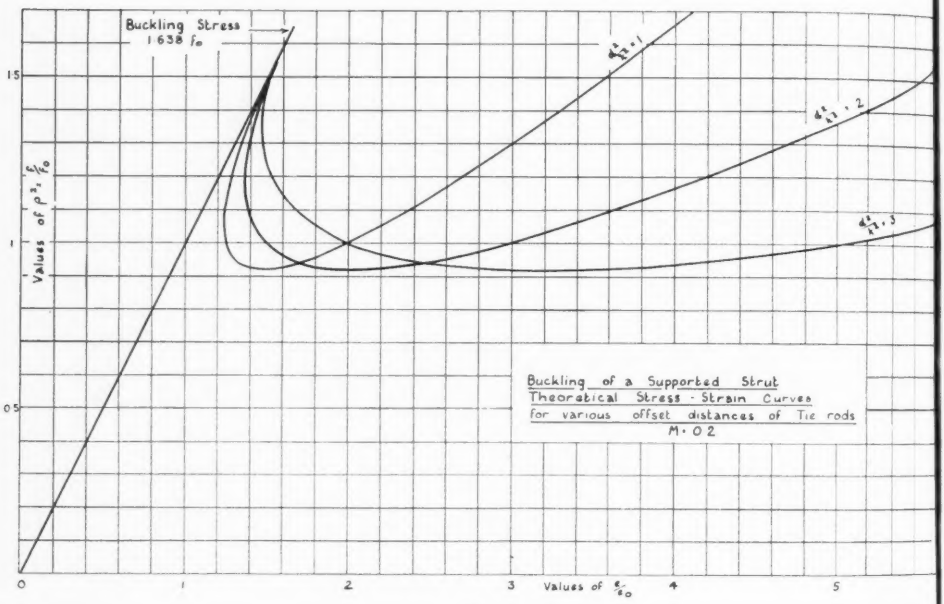


FIG. 5.

Supported strut—theoretical curve.

beyond it would be reached immediately after buckling, so that the buckle would be sudden. The general similarity between the conditions in this supported strut test and the conditions in tests on tubes and curved panels is obvious, and if a curve similar to that shown in Fig. 5 is added to Fig. 4, the resulting diagram shown in Fig. 6 appears quite adequately to explain the experimental results. It is interesting to note that the trough of the curved panel diagram corresponds roughly to the buckling load for a flat panel of the same elevation, that is, of a panel without lateral support. I have no doubt that this conception will suffice to correlate the experimental with the theoretical results for curved sheets in compression; it is probable even that the theory needs no amendment, but only extension to consideration of the behaviour after buckling. At the same time the actual analysis is likely to prove very laborious.

Until this theoretical problem has been cleared up, quantitative data as to the behaviour of curved panels in compression must be stated with some reserve. On the basis of the tests carried out at the N.P.L. (31) in the apparatus shown in Fig. 7 I have suggested the empirical formulæ for panels with clamped edges.

$$f_b = E' (6\,t^2/b^2 + 0.21\,t/r)$$

and

$$n = 1.3 + (b/100\,t)\,(1 + 2.4\,b/r)$$

where $2\,b$ = circumferential width.
$2\,t$ = thickness.
r = radius of curvature.
$E' = E/(1-\sigma^2)$.

These formulæ describe the experimental results with reasonable accuracy and they give the flat panel values as a limiting case; but I am inclined now to think that they tend to over-estimate the effect of curvature.

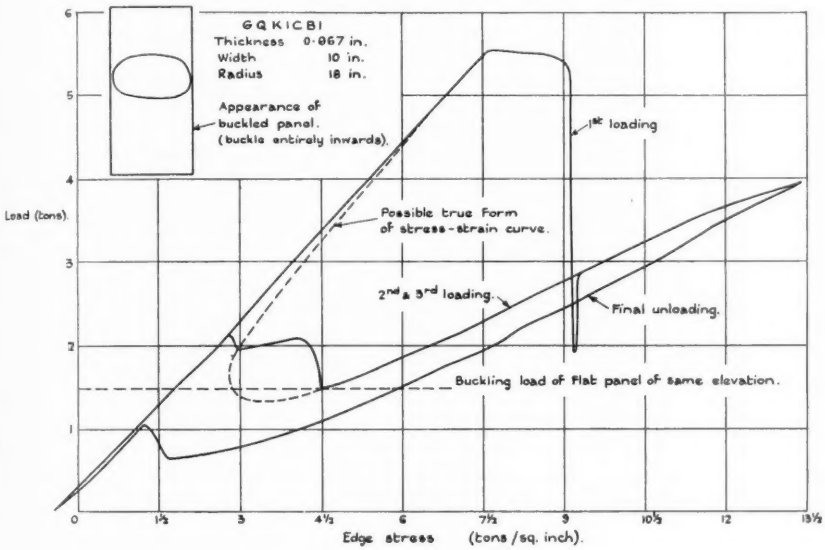


FIG. 6.

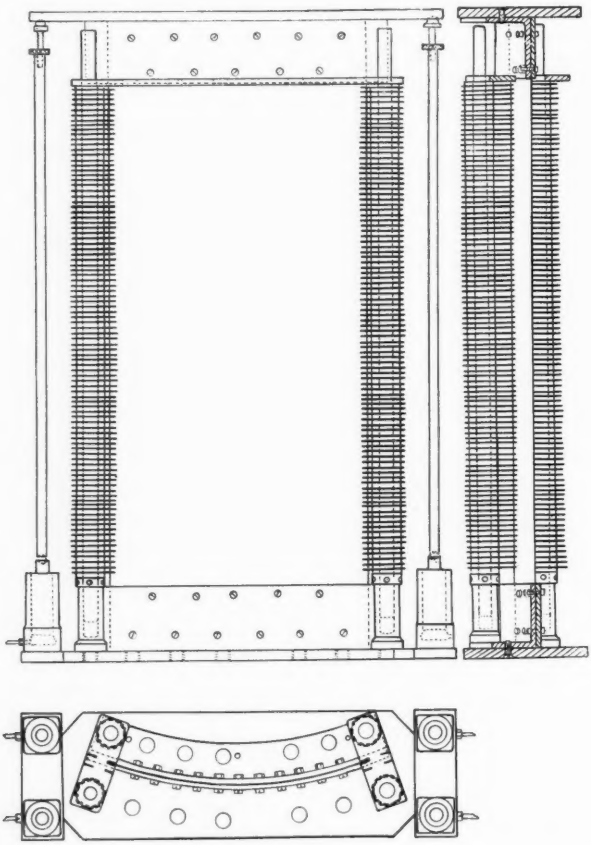
Curved panel with curve for supported strut added

At the same time the formulæ include no provision for the excess of f_b above the true buckling stress to which I have already referred, so that on balance they may be reasonably accurate. The ratio of the effective width to the actual width at a value of edge stress f_e is approximately $1/n + \{(n-1)/n\}\,(f_b/f_e)$.

3. STRESS ANALYSIS OF CYLINDERS IN BENDING.

When a monocoque fuselage is subjected to a bending moment, the first departure from its behaviour as an ordinary beam will usually be occasioned by buckling of the panels between the stringers on the compression side. The effect of this buckling is usually taken into account by the effective width method to which I have already referred; but it seems to me preferable to use the conception of f_b at n which describes the behaviour of the panels more exactly. At first sight this method may appear more complex than the effective width method, but the greater complication lies entirely in the basic analysis and the practical

application is in fact easier, in that successive approximation is not necessary. At the same time the method determines the relation between load and stress at all loads instead of at one load only. This point and the considerable accuracy which the method permits is illustrated by Fig. 8, which shows the result of analysis by the f_b and n method for the first tube tested at Bristol (4). The ordinates are the values of the apparent stress f_a, that is the stress calculated from the load and the apparent I of the tube neglecting the effect of buckling; the ordinates are thus directly proportional to the load. The abscissæ represent



Scale $\frac{1}{8}$ full size.

FIG. 7.

Curved panel apparatus.

the values of the actual maximum tensile and compression stresses f_t and f_c respectively, and so long as the stringers remain unbuckled these abscissæ may also be regarded as representing the maximum tensile and compressive strains to which the stringers are subjected.

For values of f_a up to f_b, in this case about 2.4 tons/sq. inch (the value being determined from the empirical formula), the tube behaves as a simple beam and

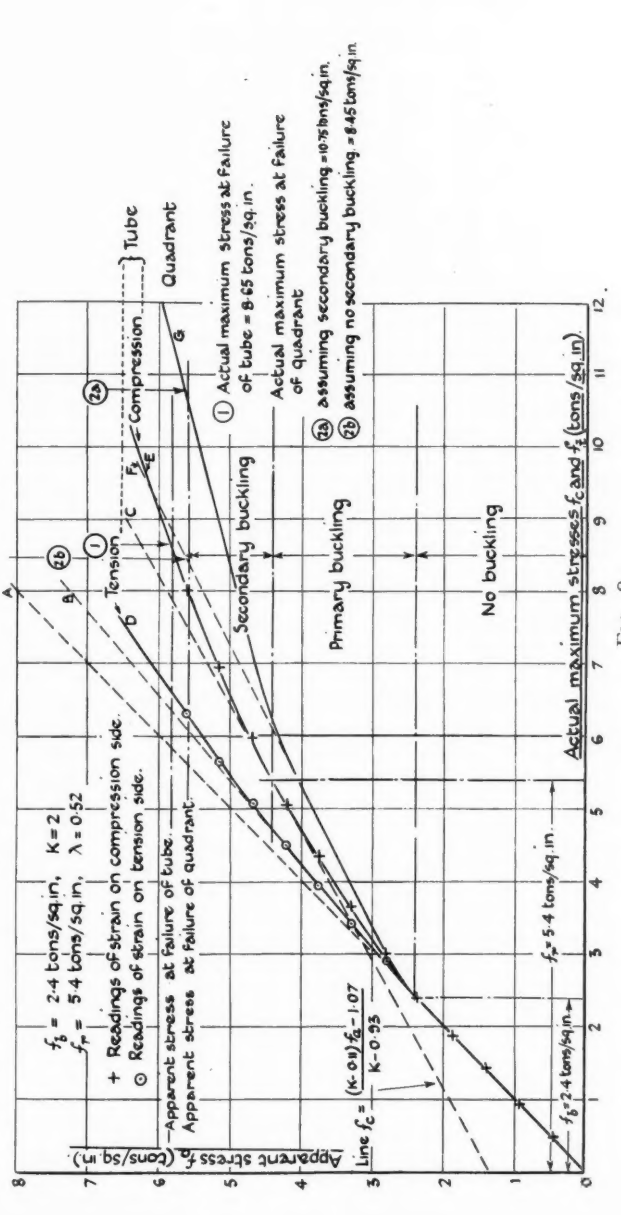

f_b = 2·4 tons/sq.in, K = 2
f_m = 5·4 tons/sq.in, λ = 0·52
+ Readings of strain on compression side.
⊙ Readings of strain on tension side.
Apparent stress at failure of tube.
Apparent stress at failure of quadrant.
Line $f_c = \frac{(K-0·13)f_b - 1·07}{K-0·93}$
Apparent stress f_b (tons/sq in.)
Actual maximum stresses f_c and f_z (tons/sq.in)
f_b = 2·4 tons/sq.in.
f_m = 5·4 tons/sq.in.
No buckling
Primary buckling
Secondary buckling
Tension
Compression
Tube
Quadrant
① Actual maximum stress at Failure of tube = 8·65 tons/sq.in.
Actual maximum stress at failure of quadrant
(2a) assuming secondary buckling = 10·75 tons/sq.in.
(2b) assuming no secondary buckling = 8·45 tons/sq.in.

FIG. 8.

Results of test on first tube.

both f_t and f_c are identical with f_a. For values of $f_a > f_b$, the buckling of the panels and the consequent reduction in their effective stiffness causes both f_t and f_c to increase more rapidly than f_a and at the same time the neutral axis of the tube moves from the central plane towards the tension side. The lines B and C of Fig. 8 represent the expected relations between f_t and f_a and f_c and f_a deduced by means of formulæ explained below from the value of n given by the empirical formula and from the geometry of the section of the tube. The agreement between the recorded strains and the $f_t - f_a$ and $f_c - f_a$ curves is at first extraordinarily good; but at higher loads the experimental readings of strain break away fairly sharply from the lines. This breakaway occurs at a value of f_c of about 5.4 tons/sq. inch, and in quoting this value I intend to emphasise that it is f_c and not f_a that matters; f_a merely represents the load, whilst f_c is the actual maximum stress, and it is stress that determines failure. Apparently then at $f_c = 5.4$ tons/sq. inch, some secondary buckling must have occurred. This buckling can scarcely have affected the stringers themselves, or failure would have ensued fairly soon after. Accordingly we must consider some type of secondary buckling of the sheet, and almost inevitably we are forced to the conclusion that the breakaway must have been due to buckling of the sheet over the stringers between rivets.

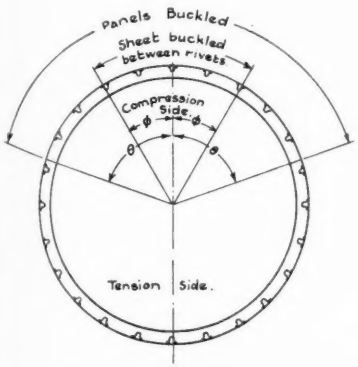
The rivet spacing was 1in. and the thickness of skin 0.029 inch, so that the stress 5.4 tons/sq. inch corresponds to a fixity coefficient of 1.7. The value of this coefficient would in any case be expected to lie between 1 and 4, and in view of the general conditions the deduced value of 1.7 appears quite reasonable, so that the subsequent behaviour has been analysed on the assumptions that the breakaway at 5.4 tons/sq. inch was due to buckling of the sheet between rivets and that at higher stresses this part of the sheet continued to carry its buckling load, but would carry no increase of load. These assumptions lead to the lines D and E of Fig. 8, and it will be seen that the agreement with the experimental readings of strain is extremely good.

The tube finally failed by collapse of the stringers most highly stressed in compression at a value of f_c about 8.6 tons/sq. inch; but the failure was attributed to local instability of the stiffener section itself. The curves F and G of Fig. 8 represent the expected behaviour of the quadrant test piece corresponding to this first tube, F being the first approximation disregarding the effect of buckling between rivets and G the final curve. Unfortunately no readings of strain of the quadrant are available for comparison; but, assuming the analysis to be correct, the quadrant test piece apparently withstood a maximum stress of 10.5 tons/sq. inch, which is appreciably greater than the stress 8.6 tons/sq. inch at which the tube failed. Presumably the conditions of loading in the two tests were not strictly comparable; but it should be noticed that despite this quite big discrepancy, the quadrant test piece still affords quite a good estimate of the strength of the tube. On the basis of the result of the quadrant test, by the f_b and n analysis the tube should have carried an apparent stress 6.4 tons/sq. inch. Actually it carried 5.8 tons/sq. inch, only 10 per cent. lower. This is an excellent illustration of the point I tried to make earlier with regard to the choice of test piece. As a further illustration I have prepared the table below.

ESTIMATES OF MAXIMUM LOAD CARRIED BY TUBE ON BASIS OF RESULT OF A TEST ON

	A Tube.	A Quadrant.	A Single Stringer
Disregarding all buckling	6.0	5.2	9.1
Taking into account buckling of the panels	6.0	5.7	6.5
Taking into account buckling of the panels and of the sheet between rivets	6.0	6.0	6.0

Consider three tests (*a*) on a complete tube, (*b*) on a quadrant test piece, and (*c*) on a single stringer, and assume that failure in each test occurs at the same value 9.1 tons/sq. inch of the actual stress f_c. Then the table shows the estimates of the maximum load the tube will carry (quoted in terms of values of f_a) deduced from the results of the three tests by each of the three methods of analysis (1) neglecting buckling entirely, (2) taking into account buckling of the panels but not of the sheet between rivets, (3) taking into account both modes of buckling. Naturally the test on the tube gives the right answer anyway, but the accuracy of the estimates obtained by the simpler tests depends on the method of analysis. The analysis (3), which we have assumed to be complete and correct gives the right answer in both cases; but the estimate obtained by methods (1) and (2) is much greater for the quadrant test than for the test on the single stringer, and moreover the estimates based on the quadrant are on the safe side, whilst the estimate based on the single stringer is always too high.



Analysis of Bending of Stiffened Tubes.

Total area of stringers = A_s
Total area of sheet attached to stringers = A_r.
Total area of panels between stringers = A_p.
Panels buckle at stress = f_b.
Effective stiffness of panels after buckling = $1/n$.

$$\frac{n}{n-1}\cdot\frac{A_s+A_r+A_p}{A_p}=K,\quad \frac{n}{n-1}\cdot\frac{A_r}{A_p}=\lambda.$$

Apparent stress = f_a.
Actual maximum compressive stress = f_c.
Actual maximum tensile stress = f_t.
Sheet buckles between rivets at actual compressive stress = f_r and $f_b/f_r=\rho$.

$$f_a/f_b=\frac{(K\pi-\theta)+\sin\theta\cos\theta}{\sin\theta+(K\pi-\theta)\cos\theta},\quad \frac{f_c}{f_b}\text{ and }\frac{f_t}{f_b}=\frac{K\pi\pm(\sin\theta-\theta\cos\theta)}{\sin\theta+(K\pi-\theta)\cos\theta}$$

For values of $f_a > 1{\cdot}5\,f_b$, $f_c=\dfrac{(K-0{\cdot}11)\,f_a-1{\cdot}07f_b}{K-0{\cdot}93}$

For values of $f_c > f_r$.

$$f_a/f_r=(1-\rho)\{K\pi-(\theta-\sin\theta\cos\theta)-\lambda(\phi-\sin\phi\cos\phi)\}/K\pi(\cos\phi-\cos\theta).$$

$$f_c/f_r=\{(1-\cos\theta)-\rho(1-\cos\phi)\}/(\cos\phi-\cos\theta).$$

$$\text{where }(1-\rho)\{\sin\theta-\theta\cos\theta+\lambda(\sin\phi-\phi\cos\phi)\}=K\pi(\rho\cos\phi-\cos\theta).$$

FIG. 9.

Analysis of tubes.

I have yet to explain how the method of analysis I have termed the f_b and n method is to be applied. For this purpose I have prepared the rather overcrowded Fig. 9. The method is based on a very useful device, which can best be described as "starting in the middle." In this case we start by assuming that the distribution of stress is such that all the panels included within an angle 2θ on the compression side are buckled, so that the stress at θ is f_b. All the stringers, such part of the sheet as may be regarded as integral with the stringers, and all the panels outside the angle 2θ carry the full stress f corresponding to the strain (f varying round the tube). The panels within the angle 2θ carry the stress f_b plus $1/n$th of the excess $f-f_b$, *i.e.*, $\{(n-1)/n\}f_b+(1/n)f$. Now consider all the material of the tube distributed round its periphery as a sheet of uniform thickness, the total area of section being made up of A_s total area of section of the stringers, A_r total area of section of sheet integral with the stringers, and A_p total area of section of panels.

A_s, A_r and $1/n$th of A_p always carry the full stress f, $\{(n-1)/n\}A_p$ carries f if $f < f_b$ (compressive stress reckoned positive) or f_b if $f > f_b$. Since f_b is constant it is quite easy to calculate (on the usual assumption that plane sections remain plane) the moment (represented by f_a) and the maximum tensile and compressive stresses f_t and f_c as functions of the angle θ at which $f = f_b$. These functions for a circular tube are shown in Fig. 9; but the functions can easily be tabulated numerically against θ, or any other convenient variable, for a tube of any section. Values of f_t and f_c corresponding to values of f_a are thus obtained and f_t and f_c can be plotted against f_a without further reference to θ. In the case of the circular tube, the relation between either f_t or f_c and f_a for values of $f_a >$ about $1.5\ f_b$ is very nearly linear, so that for this section the relation between

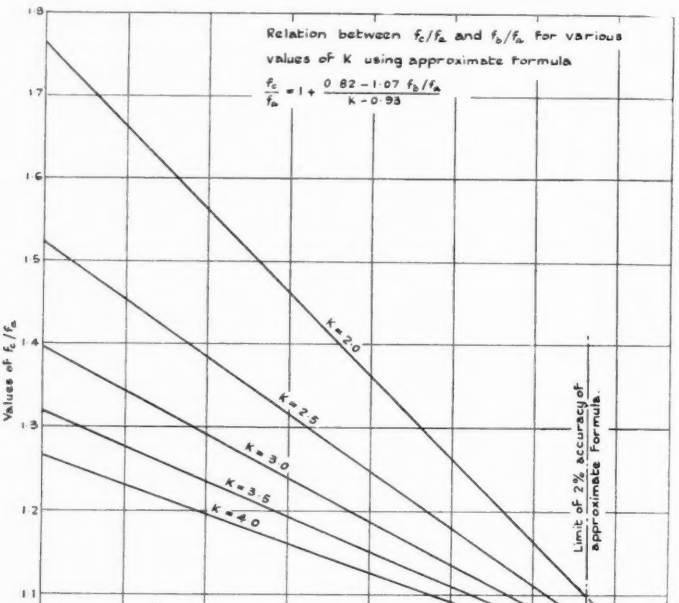


FIG. 10.

K curves for tubes of circular section.

f_c, f_a and f_b for values of $f_a > f_b$ can be expressed by the approximate formula shown in Fig. 10. It is probable that similar simple formulæ could be found for tubes of other sections. The constant K on which alone the approximate formula depends is the ratio of the total area of section to the "limited load" area $\{(n-1)/n\}A_p$. The diagram Fig. 10 gives the value of the ratio f_c/f_a for any circular section tube for which the values of f_b/f_a and of K are given. A similar diagram could easily be prepared for any other shape of section.

The effect of secondary buckling can be taken into account by an exactly similar method, but now we have the two variables θ and ϕ corresponding to the two points at which $f = f_b$ and $f = f_r$ respectively, f_r being the value of f at

which secondary buckling occurs. Formulæ for this case are necessarily more complicated and one implicit relation between θ and ϕ has to be satisfied. Since the values of K, λ (the area ratio appropriate to secondary buckling) and the ratio $\rho = f_b/f_r$ are known, it is easy, by assuming values of ϕ, to calculate the corresponding values of θ; by insertion of these corresponding pairs of values of θ and ϕ in the formulæ for f_a and f_c, corresponding pairs of values of these latter variables are obtained. The whole process is more difficult to describe than to perform, and, as in the simpler case, application to tubes of non-circular section would present no special difficulty.

Strictly, even when the stringers themselves begin to buckle, collapse will not occur until sufficient stringers are involved to cause f_a to commence to fall as f_c is increased. For extreme accuracy, therefore, stringer buckling should be treated in the same manner as yet a third mode of buckling and collapse should be expected when the $f_a - f_c$ curve thus finally corrected becomes parallel to the f_c axis. However, apart from the effect of special restraint of the type I shall consider in a moment, the increase of f_a above the value when the most highly stressed stringer begins to buckle is unlikely to be considerable, so that this refinement appears scarcely justified.

In further illustration of the power of this f_b and n method, its application to the results of the test on the second tube tested at Bristol is shown in Fig. 11. The values of f_b and n have again been estimated from the results of tests on simple panels; but the value taken for f_b is rather lower than that indicated by the empirical formula. This value was adopted before the results of tests on panels had been analysed. Actually a slight increase of f_b would improve the agreement with the experimental results; but, since the value is in any case small, the difference is not very great. The value of f_r has been calculated, using the same value of the fixity coefficient of the sheet buckling between rivets as that found appropriate in the previous case. The agreement between the theoretical and experimental results is not quite so good as for the first tube, the readings of compressive strain at high load tending to exceed the theoretical estimate. This slight disagreement might reasonably be disregarded; but in fact it suggests the commencement of a third mode of buckling and thus provides most valuable evidence in relation to the point which I wish now to discuss.

4. Ultimate Stress Carried by Stringers Attached to Sheet.

(*a*) *General.*—Detailed analysis of the stresses set up in a tube in bending is of no particular value unless we know the maximum stress that is permissible. Now it seems to me that the stringer cannot carry a stress greater than that which would buckle it if it were tested alone as a strut; providing only that in that test it did not buckle sideways in the direction parallel to its plane of attachment to the sheet. I recognise that this is a daring statement, but the results of the test on the first tube and on its corresponding quadrant at least do not contradict it. The calculated Euler stress for the stringers of this tube simply supported between frames is about 20.2 tons/sq. inch; the actual stress at failure was 8.6 tons/sq. inch for the tube and 10.5 tons/sq. inch for the quadrant; but this is scarcely good evidence because the stringers of this tube failed primarily owing to local instability. In the case of the second tube, however, the Euler stress is only 9.2 tons/sq. inch, whereas the stringers in the tube apparently carried 11 tons/sq. inch and in the quadrant possibly as much as 13 tons/sq. inch. The actual theoretical estimates of the failing stress, obtained by a method applicable to flat construction, which I shall explain in a moment, are 12.1 tons/sq. inch for the first tube and 6.2 tons/sq. inch for the second. On the other hand, at values of f_c above about 7 tons/sq. inch, the recorded strain readings do suggest that some third mode of buckling was in process, and since the sheet was already completely buckled it seems that this third mode must have involved the stringers.

(*b*) *Effect of Curvature.*—If buckling of the stringers began, why did not collapse ensue very soon afterwards? I think the most probable explanation is that illustrated in Fig. 12. In a flat construction, deflection of the stringers in either sense stretches the sheet in the transverse direction only by amounts proportional to the difference of the deflections of the stringers. In a fairly wide stiffened panel, even if the edge members are held straight, quite a large deflection of the central stringer is possible with only a very small transverse extension. In the case of a curved construction, however, the conditions are essentially different. For small deflections, the stringers have actually more freedom because at first the motion is restricted only by the curvature of the sheet and transverse direct stress is not set up until the deflection is fairly large. On the other hand, when transverse stresses are set up by outward bowing of the stringers, their rate of

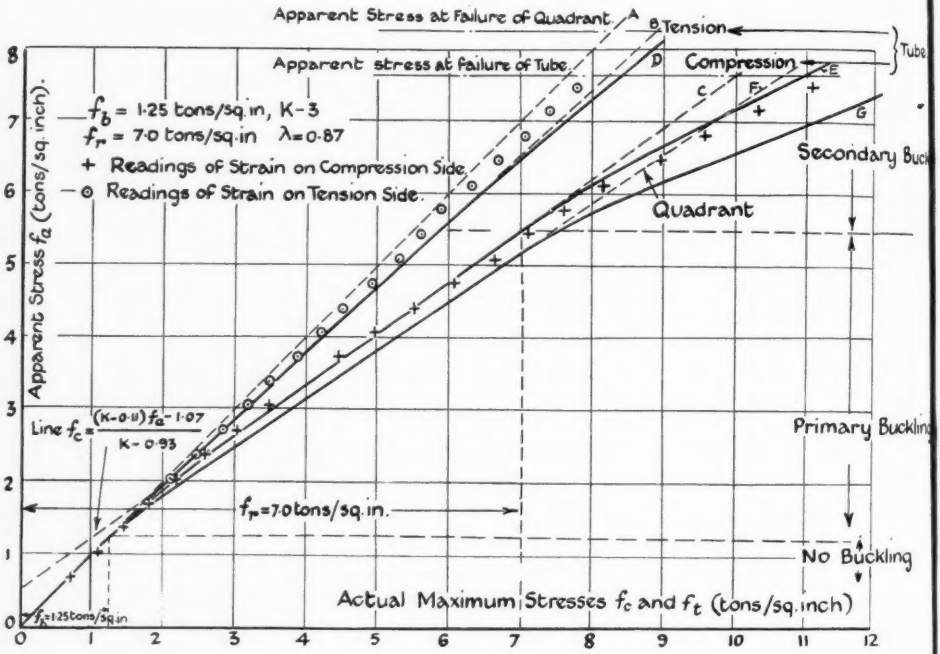


FIG. 11.

Results of test on second tube.

increase with stringer deflection is much greater and the restraining influence of the sheet is consequently much more considerable.* In Fig. 12, the "free" movement δ of the point of maximum deflection of the stringer is shown for three different modes of buckling. If all the stringers between one pair of adjacent frames were to buckle outwards, the possible free movement would be small, if one only buckled outwards the free movement would be about doubled, and if alternate stringers buckled in and out the free movement would be about doubled again; if all the stringers buckled inwards, no transverse stress would be set up.

Now, in assuming the stringers to be simply supported at the frames, we imply that they buckle alternately inwards and outwards between successive frames.

* Attention to this effect was drawn by Mr. A. E. Russell in a lecture to the Cambridge Engineers' Association, 1938.

Consequently some are subject to one or other of the restraints on free movement, and if this free movement is so small that elastic failure of the stringer in bending does not occur before this free movement is exhausted, collapse must in part depend on the restraint due to transverse stress in the sheet. The maximum free movement in the chess board buckling pattern corresponds in the first tube to a maximum bending stress in the stringers of 54 and in the second to 14 tons/sq. inch.

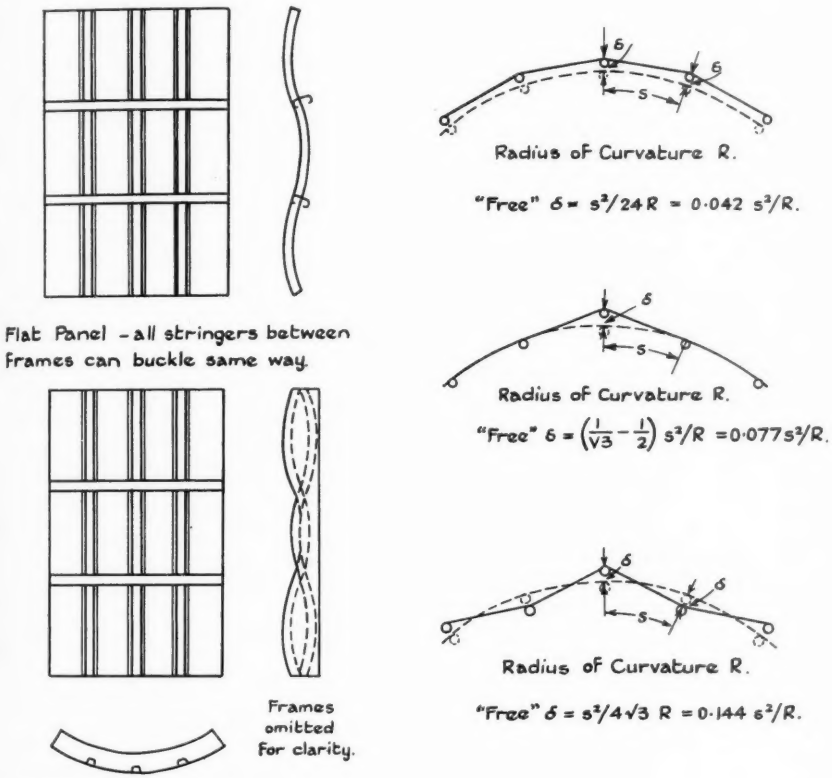

Flat Panel - all stringers between frames can buckle same way.
δ
δ
s
Radius of Curvature R.
"Free" δ = s²/24R = 0·042 s²/R.
δ
s
Radius of Curvature R.
"Free" δ = (1/√3 − 1/2) s²/R = 0·077 s²/R.
δ
δ
s
Radius of Curvature R.
"Free" δ = s²/4√3 R = 0·144 s²/R.
Frames omitted for clarity.
Curved Panel - stringers. probably buckle in "chess-board" manner.

FIG. 12.

Chess-board buckling of stringers.

Clearly, therefore, this curvature restraint is unlikely to have affected the failure of the first tube, but may easily have influenced the second. This explanation implies that the stringers of the second tube started to buckle at 6.2 tons/sq. inch. In the actual test in and out waving of the stringers was observed at a value of f_s of 7 tons/sq. inch, and the effect of this waving in causing increase of the strain is apparent in Fig. 11. In the final failure no stringer buckled outwards, although

several were buckled inwards. On this evidence it is reasonable to conclude that the increase of the actual buckling stress above the expected value was due to the restraint due to curvature.

(c) *Fixity Effect at Frames.*—In discussing the stability of the stringers, I have already tacitly assumed that the end fixity restraint due to the torsional stiffness of the rings is negligible. In the case of the tubes tested at Bristol this assumption is entirely justified, for the torsional rigidity of the rings in these tubes was very small. In general, for a grid of ribs and stringers without sheet covering (54), it can be shown that the fixity coefficient lies between 1 and $1+(1/\pi^2)\,(b/d)\,(CJ_R/EI_s)$, where $2b$ and $2d$ are the spacings of the ribs and stringers respectively, CJ_R is the torsional rigidity of the ribs and EI_s is the flexural rigidity of the stringers. For all practical constructions this maximum possible increase is likely to be very small.

(d) *Interaction of Sheet and Stringer.*—It remains then to discuss the effect of interaction between the sheet and the stringer on the stress at which the stringer buckles. Consider a single panel of cross-sectional area A with its edges simply supported and of such a form that it will buckle in compression in one wave at a stress f_b. Now take a strut of the same length as the panel composed of two top hat sections riveted back to back with spacing washers of thickness equal to that of the panel. Let the area of this strut be A' and let its buckling stress be f_s. Next take the two halves of the strut and rivet them one on either side of the panel down its centre line. What load and what stress will the combination carry? Since the wave form of the buckled strut tested alone is the same as the wave form of the centre line of the buckled panel tested alone, the total load carried at buckling of the stringer is equal to the sum of the loads carried separately; but the load is shared quite differently, the panel carrying much more and the stringer the same amount less. Failure occurs at a stress f_c intermediate between f_b and f_s and a proportion $1-f_c/f_s$ of the load the stringer would carry alone is actually carried by the sheet. The actual value of f_c in relation to f_b and f_c depends on the ratio A/A' and on the values of f'_b and n which determine the behaviour of the half panels into which the original panel is divided by the stringer. If $f'_b > f_c$ so that the stringer buckles before the side panels

$$f_c=(Af_b+A'f_s)/(A+A');$$

but if $f'_b < f_c$, the actual value of the collapsing stress f'_c will be somewhat greater. As a fairly rough approximation we may take

$$f'_c=[(H+1)\,f_c-\{(n-1)/n\}\,f'_b]/(H+1/n),\ \text{where}\ H=2A'/A \quad (55).$$

In this analysis I have assumed, firstly, that the panel without the stringer would buckle into a single half wave and, secondly, that the neutral axes of the stringer and panel coincide. With regard to the former assumption, in a flat construction a sufficient width of panel to buckle in one half wave between adjacent ribs could be obtained in all but very exceptional cases by including more than one stringer. This change does not necessitate any essential alteration in the argument. To curved constructions this argument is not applicable, but in any case the buckling of struts attached to curved panels is considerably influenced by the effect of cross tensions, and simple discussion of this problem is not possible. There is still considerable scope for investigation of this problem. With regard to the second assumption as to the coincidence of the neutral axes of the stringer and sheet, I think the effect of the sheet in increasing the flexural rigidity of a stringer attached on one side only is usually very much overestimated. In Fig. 13 I have plotted the radius of gyration for a sheet stringer combination for various associated widths of sheet and various ratios of the distance between the neutral axes of sheet and stringer to the radius of gyration of the stringer alone. Only if this ratio is high and the amount of sheet added fairly small is the radius of gyration of the combination greater than that of the stringer alone; and a high ratio of offset distance to radius of gyration implies

an inefficient stringer. A high ratio could only be obtained efficiently by making the stringer top heavy, with a heavy outer flange and a light inner one; but this raises difficulties with regard to local instability and renders attachment of the stringer to the sheet more difficult.

(*e*) *Local Instability.*—So far in discussing the stability of the stringers, I have not referred to the possibility of local instability, where a portion of the stringer, as for instance an outstanding flange, buckles independently. The theory of this type of instability, of which torsional instability is an important case, is fairly well understood theoretically (40-52) and the results of experiments, most of them carried out in America (47) generally confirm the theoretical results. The only point I wish to make in this connection is that the appearance of the stringer after collapse is not a safe guide as to whether it failed by local or general instability. I suspect that many constructions using stringer sections formed from thin sheet may have failed by local instability, although the final collapse may have suggested overall instability. This point was illustrated in the test on the first tube at Bristol.

(*f*) *Overall Instability.*—Finally, in relation to failure in bending, I come to the question of overall instability in which both stringers and ribs may be deflected. In the first place, I want to point out that, if the liability to this kind of instability is entirely absent, the ribs are for this purpose unnecessarily heavy or too closely spaced. In fuselages the section and spacing of the ribs may be

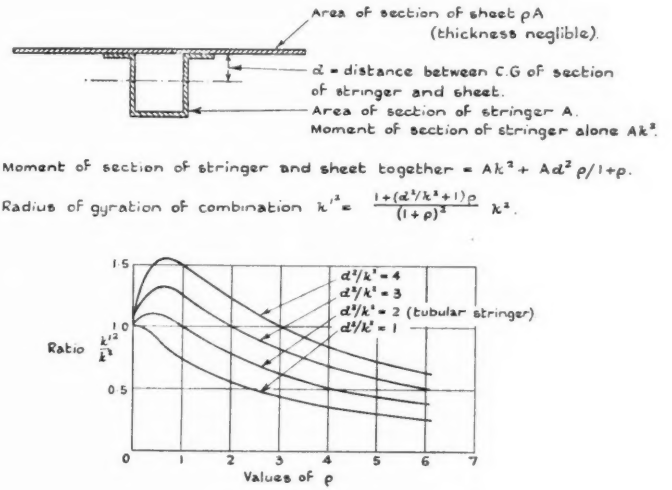


FIG. 13.

Effect on radius of gyration of adding sheet to stringer.

determined by considerations of stresses due to torsion or of resistance to local loading; but in wing structures at least neither of these considerations is likely to determine the design. The complete and exact solution for the overall instability of a curved framework of ribs and stringers covered with thin sheet is probably unattainable; but two simplified treatments have been developed which indicate the nature of the governing conditions. In one treatment, the flexural and torsional rigidities of the stiffeners are considered to be distributed over the whole surface of the structure and the stability of the resulting orthotropic sheet is discussed (53). In the other treatment the sheet covering is ignored and the stability of the grid of stringers and ribs alone is discussed (54). Both treatments

yield results of the same general form; but there are two important differences between them, which in relation to the usual conditions and requirements for aircraft structures, seem to me to render the second treatment preferable.

A uniform isotropic sheet with supported edges buckles into a form in which any section parallel to either pair of edges is a sine wave; the same statement is true also for an orthotropic sheet. In the case of a grid of stringers and ribs the buckled form is such that the points of intersection of the stiffeners lie on a double sine wave surface; but the form of the ribs in between these points of intersection are necessarily cubic curves, whilst the form of the stringers are also not pure sine waves. Moreover, the wave length in the direction of the compression is for the orthotropic sheet proportional to the free width, and although it is also related to the degree of anisotropy, it is not related directly to the spacing

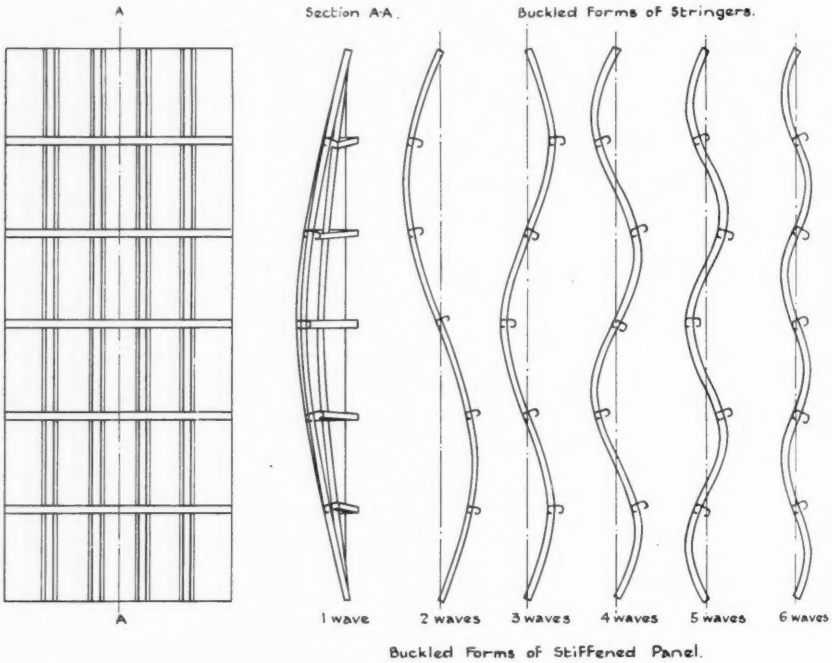


FIG. 14.

Overall buckling of ribs and stringers.

of the ribs. In the case of the grid of stringers and ribs, on the other hand, the mode of buckling most likely to occur is that in which the number of half waves down the length of the grid is one less than the number of panels. This point is illustrated in Fig. 14, which shows the six possible modes of buckling of a flat stiffened sheet of six rows of panels; it should be noticed that buckling in five waves might to fairly casual inspection be confused with buckling in six. However stiff we make the ribs, we cannot make the structure carry a stress greater than that required to buckle the stringers between ribs, so from a practical point of view the most useful information is the necessary stiffness of the ribs to prevent buckling at any stress below this limit.

Taking the six-row structure in Fig. 14, it is clear that at a stress 1/36th of the limit stress, buckling in one wave becomes possible. For loads above this

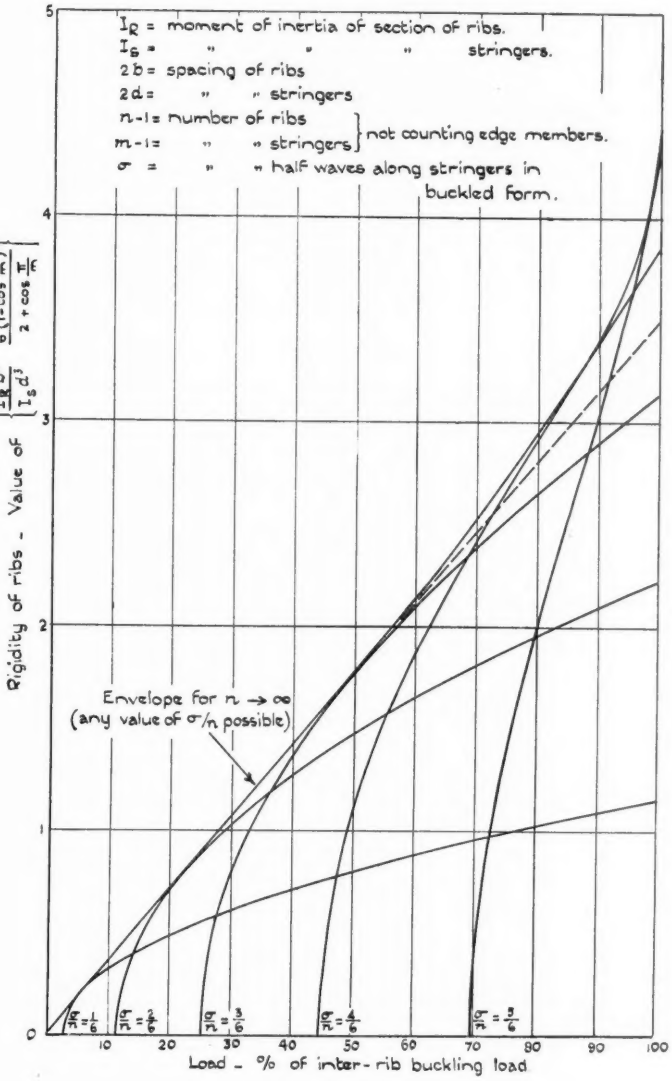


FIG. 15.

Stiffness ratios to prevent overall buckling.

lower limit a certain stiffness of ribs is necessary to prevent this type of buckling. This requisite stiffness increases with the load at first rapidly and then more slowly until at some load greater than 1/9th (*i.e.*, 4/36ths) of the ultimate a still greater stiffness becomes necessary to prevent buckling in two half waves. Similarly, at some load greater than $\frac{1}{4}$ (=9/36) the ultimate liability to buckling in three waves becomes the determining factor and so on. The general relationship of necessary rib stiffness to load is shown in Fig. 15. The successive curves for each mode of buckling in this figure at first envelope a straight line; the orthotropic treatment indicates this straight line as the complete solution. But you will see that in Fig. 15, the final curves for buckling in four or five waves rise very steeply above this line, until at the ultimate load the grid solution indicates a necessary rib stiffness 60 per cent. greater than that suggested by the orthotropic treatment. This difference is certainly due to the marked deviation of the stringer form from the pure sine wave at these high loads. If the rigidities of the stiffeners were small in comparison with that of the sheet, the orthotropic treatment would probably be more nearly correct; but, if the stiffeners are relatively more important, and they will normally be so in aircraft structures, the grid treatment is more reliable.

5. Stress Analysis of Cylinders in Torsion.

In a monocoque tube subjected to torsion, it is usual to assume that the shear is carried entirely by the sheet covering; the intrinsic resistance of the stiffening members is likely to be very small, so that this assumption is probably entirely justified. In tubes of non-circular section, particularly tubes representative of wing structures, the distribution of shear stress in the sheet will not usually be uniform and may be considerably influenced by the effect of end constraints. This problem is receiving a great deal of attention at the present time and it is not worth while to attempt to review the present state of knowledge. The position should be much clearer at the conclusion of the experiments now being carried out at the R.A.E.

For the moment I shall restrict my attention to the case of the fuselage, of which the section is usually not far from circular, so that the effect of end constraint is not important. Here again, the first departure from the ordinary elastic behaviour will be occasioned by buckling of the sheet in the panels between the stiffening members, and again in flat panels this buckling will occur at a stress $s_b = KE\,(t/b)^2$, where t is the thickness of the sheet and b the minimum superficial dimension of the panel. The value of the constant K for different edge conditions has been determined theoretically (15, 17) and the values, with certain important reservations for high values of t/b (16), have been confirmed by experiments. In the case of curved panels the theory (29) is complex and the results are not easy to state in a simple form; but approximately the buckling stress may be represented by an expression similar to that given by Redshaw for buckling in compression (28), or more simply still merely by adding a term $K'E\,(t/r)$ to the expression for the buckling stress of a flat panel of the same elevation. Theoretically, the best values of K' for a long narrow strip appear to be about 0.3 for simply supported edges and 0.2 for clamped edges; in the latter case, however, the formula

$$s/E = 0.3\,t^2/b^2 + \sqrt{\{\,3.17\,(t^4/b^4) + 0.03\,(t^2/r^2)\,\}}$$

is considerably more accurate. Very few results of tests of curved panels in shear are available (33), but they indicate that the experimental value of K' may be considerably below the theoretical value. However, in the case of shear, on the basis of the methods of analysis now generally in use, the actual value of the buckling load is not of great importance. Buckling of the panels will normally occur at loads well within the working range, and again the behaviour after buckling has to be considered. In buckling, corrugations are formed in the panel more or less parallel to the direction of the principal tension in the sheet, and

the resulting curvature of the sheet in the perpendicular direction greatly reduces its resistance to the associated compression. If the resistance to compression were entirely annulled, the panel might be represented by a system of parallel wires and the structure would become a rather special type of braced frame. This treatment is, in fact, that adopted by Wagner (24) and it has been developed in some detail by him and his collaborators (25). Since this work is well known, I shall only refer briefly to the application of the treatment to the case of the fuselage. The diagonal tension in the sheet causes a uniform inward radial loading $Tts \sin^2 \alpha/2\ R$ per unit length and an axial thrust $Tts \cos^2 \alpha$ to be applied to the stringers, where T is the tension in the sheet, t its thickness, s the stringer spacing, R the radius of curvature of the tube, and α the angle between the tension field waves and the stringers. The stringers are supported and by symmetry may be considered clamped at the frames, so that the stresses in the stringers can be determined by the ordinary beam formulæ. The reaction on the frames consists of a system of inward loads, and here again the stresses can be found by ordinary methods. Both sets of stiffeners will of course strain; but the effect of these strains in modifying the stress distribution of the sheet will probably be negligible in all practical cases.*

There is a theoretical possibility that the frames may become unstable under the system of inward normal loads; but in practice it is probably safe to ignore this possibility. I do not think that theoretical analysis of the conditions under which such instability might occur has been worked out; but the problem should present no special difficulty. If the fuselage is subjected to combined bending and torsion, the end loads in the stringers on the compression side may considerably increase the stress due to the bending load imposed by the sheet; but this effect can be assessed theoretically if the buckling stress of the stringer is known. A certain amount of experimental evidence on the failure of tubes under combined bending and torsion is available (4, 47); but the results do not appear to have been critically analysed on a stress basis. Complete failure of the tube in torsion can only occur by elastic failure of the sheet, but elastic failure of the stringers under the bending loads imposed on them would probably occur first and would be considered to constitute failure since the resistance of the tube itself to bending would then be negligible.

Shear associated with bending must also be carried almost entirely by the thin sheet covering. The distribution of this stress round the contour of the tube can be determined by ordinary methods, and the associated effect consequent upon buckling by which the stringers are subjected to bending is similar to the torsion case. In practice, however, the stresses due to shear are likely to be fairly small, so that from the point of view of strength this aspect of the problem is not of great importance. On the other hand, the shear deflection may be quite appreciable (48).

6. Effect of Holes and Concentrated Loads.

(*a*) *General.*—So far I have dealt only with the complete monocoque tube under distributed stress and I have ignored the two important practical problems of holes and concentrated loads. In the case of holes, the problem is to devise means by which the loads which would ordinarily be transmitted across the hole may be carried round its edge. Since this implies partial concentration of the load, the problem is very similar to that of the concentrated load. In practice, however, it is probably convenient to distinguish between the small hole which concerns only a region of uniform stress and the large hole of which one side may be in a tension region and the other in compression. In this sense the large hole really represents a complete break in the structure and its effect can only be treated as a system of concentrated loads; but the small hole permits more simple treatment.

* But it is taken into account in Wagner's analysis.

(*b*) *Stiffening of Small Holes.*—Theoretically it is possible to replace the material cut away by stiffening structure disposed wholly outside the contour of the hole and having the same essential stiffnesses as the material cut away. In this case the stress distribution in the rest of the monocoque is not altered and provided the stiffening structure itself is not overstressed, the full strength of the monocoque is conserved. Unfortunately the weight of this stiffening structure will normally be impracticably great. In the case of a sheet in shear, for instance, the necessary stiffening to annul the effect of a circular hole can be provided in the shape of a plain ring, but the weight of the ring must be five or six times the weight of the disc of sheet removed (65). Accordingly, in practice a lighter system is normally used with the result that additional stress is thrown on the monocoque (4, 66). On the other hand, this increase of stress round the hole is localised in its immediate neighbourhood and if the determining factor is stability, the extra support afforded by the stiffening structure may enable a higher stress to be carried. In cases of shear and tension, since most practical structures have some reserve of strength to these types of loading, a slight concentration of stress may not cause premature failure, so that in general a lighter stiffening system than that required to conserve the full rigidity may be acceptable. The necessary weight of stiffening structure in relation to the permissible increase of stress can be determined on the lines of the analysis developed by Mr. Gurney; but it is not possible to summarise this method in a simple manner, and I would refer you to the original paper (66).

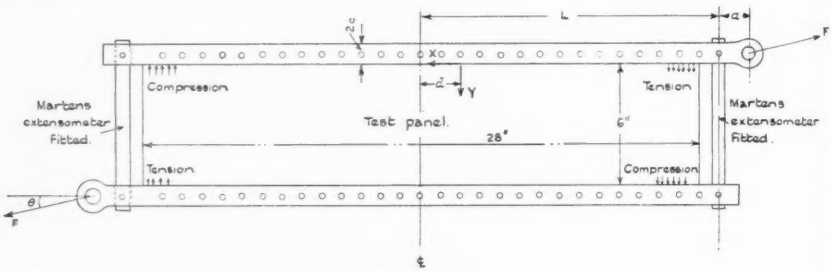


FIG. 16.

Apparatus for shear tests.

(*c*) *Effect of Tension Diagonal Stresses on Edge Members.*—Consideration of the effect of holes must also include consideration of the effect on the edge members of tension diagonal fields in the sheet; but this aspect of the problem is particularly important in relation to large holes where the main stresses are necessarily carried as concentrated loads. Practical experience has shown that the actual loads imposed on the edge members must be markedly less than the values indicated by Wagner's theory; but the reason for this difference is still somewhat uncertain. Under lateral loading the edge members will naturally tend to bend, and by bending they will tend to reduce the tension in the sheet webs; but this implies a reduction in the effective shear carried by the sheet, and unless there be some other fairly stiff structure in parallel, to which the shear can be partially transferred, the net effect of bending of the edge bars can only be to alter the *distribution* of lateral load without affecting its total amount. In so-far as the redistribution may increase the lateral loading at the supported ends of the edge members and reduce it in between, some reduction of stress in the edge members may result; but in practical cases it appears unlikely that this effect would be considerable. Moreover, if it is considerable, there is serious danger that the sheet itself may be overstressed locally.

The ratio of the lateral loading on the edge members to the shear load is proportional to the tangent of the angle which the waves in the sheet make with the

edge members. This angle may vary from the Wagner value of about 40°, but again in practical cases the variations observed are not large. Finally there is the consideration that Wagner's theory is strictly applicable only to infinitely thin sheet and that in any sheet of practicable thickness, small shear loads are carried in pure shear (27). It is natural then to expect that the lateral loading on the edge members, which is zero below the buckling load, should increase progressively from zero when the buckling load is exceeded and should tend to the Wagner value only at very high shear loads. In a preliminary examination of this effect at the N.P.L., we tested two sheets in shear in the manner shown in Fig. 16. By measuring the loads in the two distance pieces by which the edge members were held apart, we were able to determine the magnitude and position of the resultant lateral load Y on the edge members. Owing, presumably, to the effect of the

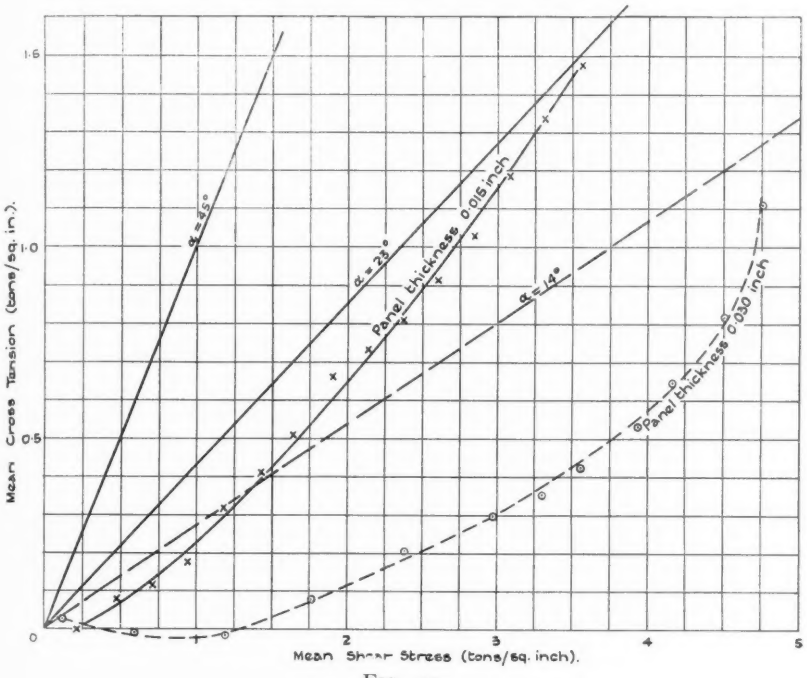


FIG. 17.

Lateral loads against shear loads.

short edges of the panels being entirely free, the observed angles between the waves formed in the sheet and the edge members were abnormally small; for this reason the curves of lateral load against shear load shown in Fig. 17 must be compared with the lines $\alpha = 23°$ for the thin sheet and $\alpha = 14°$ for the thick sheet which represent the Wagner relations between lateral and shear load for these two angles. The accuracy of this method of test is not very great, but the curves of Fig. 17 conform quite reasonably well to the expected behaviour. The theoretical buckling stress for an infinite strip similar in section to the thicker panel is 2.7 tons/sq. inch. The effect of initial irregularities in causing noticeable waving at lower stresses and the probable reduction due to the effect of the free edges of the panel render the experimental value of 1.3 tons/sq. inch quite reasonable. On the basis of this value for the thicker sheet the thinner sheet should

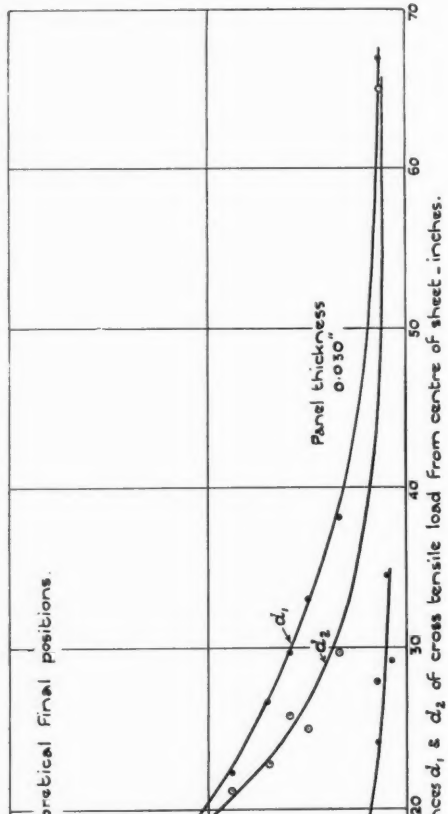


FIG. 18.

Position of lateral load.

buckle at 0.3 tons/sq. inch; the experimental value was 0.25 tons/sq. inch. In the case of the thinner sheet the gradual approach to the Wagner ratio was quite clearly marked; but for the thicker sheet the approach was much slower.

Referring again to Fig. 16 we see that, owing to the free edges of the panel, the shear stress must vary from zero at the ends of the edge members to a maximum value at the centre. Even before the panel buckles, this variation of shear stress along the edge necessitates a variation of tension *across* the panel. As a result the corners of panel nearest the load are subjected to cross tension and the opposite corners to cross compression. The resulting bending moment on the edge bar compensates the moment due to the inclination of the force F. For this reason the position of the resultant lateral load shown in Fig. 18 is at low loads outside the panel, but as the load is increased it moves inwards until at the highest loads the positions on the two edge bars are very close to the points of intersection with the edge bars of a line through the centre of the panel parallel to the direction of the waves. The displacement from this position in the case of the thinner panel was probably due to a slight slack in the panel at one end.

This investigation indicated that the transition from pure shear to tension diagonal field was worth investigation; but it seemed desirable to use a method in which the practical conditions could be more closely represented and by which more detailed knowledge of the distribution of lateral load on the edge bars could be obtained. With this object an investigation by the photo-elastic method is now being attempted.

(*d*) *Diffusion of Concentrated Loads.*—The diffusion of concentrated loads into monocoque structure is an acute case of a very general engineering problem, the solution of which is usually very difficult. In many instances, it is sufficient to appeal to St. Venant's principle to prove that the effect of local loads differs from that of distributed load only in the immediate vicinity of the loads themselves; but in a two-dimensional structure loaded along one edge, the difference may be expected to be appreciable for a length at least equal to the length of the edge. In the case of the monocoque structure, therefore, St. Venant's principle is not of much assistance, for so much of the structure is within the field of local effect that the design of this portion of the structure becomes crucial. Thus diffusion of concentrated load into monocoque structure really involves the design of a special diffusing structure which shall serve to transmit the concentrated load as a more or less distributed load to the monocoque proper (70). This diffusing structure may be quite different from the true monocoque, for instance it may take the form of a fan of tie rods or struts; but even when it is similar to the monocoque, its function is still entirely different. From the point of view of stress analysis the simplest type of diffusing structure for direct load is undoubtedly the fan type structure. This type has been used, but it involves a number of problems of detail design which are not easily solved so that its theoretical superiority to other types probably cannot be realised in practice. The method most often adopted in practice and to which the chief attention of research workers has been directed is that in which the concentrated loads are applied to longerons of sufficient section substituted for the ordinary stringers and diffusion is effected by shear in the sheet covering. This method is sometimes modified by the addition of a cross beam at the concentrated load; but this modification is likely to do more harm than good (71).

Solution of this case by approximate methods has been attempted by several workers, who have all based their analyses on the following assumptions:

(*a*) That the direct load is carried entirely by the stringers and the sheet immediately adjacent to them.

(*b*) That the load is transferred from stringer to stringer by shear in the sheet covering.

(*c*) That the bending deformation can be separated from the shear deformations due to local transfer from stringer to stringer.

The system of equations to which these assumptions lead ensures that the total load on any cross-section is constant, and, for a plane structure subjected to concentrated loads at its edge members, (*c*) ensures that the bending moment is also constant; but in all other cases constancy of the bending moment (unless it be zero) is not assured. This partial failure of the present method is due to the neglect of the cross tensions in the sheet which must be present if the shear stress varies along the length, and the adequacy of the method is restricted to cases in which these cross tensions are either absent (75) or self-balancing (73). A complete solution in which the effect of cross tension would be included presents very considerable difficulty, and the complexity of the solution would probably render it practically valueless. However, the present method is applicable to the case of a box of rectangular section loaded at the ends of members at its corners, and the errors introduced if the sides of the box are slightly curved are probably not important. The method is thus applicable to the typical wing structure, but in relation to the detachable fuselage it is unlikely to be sufficiently accurate. In practice the application of the method is still further restricted to stringers and longerons which are either of constant cross-section or tapered in such a manner that the stress in them is constant; other cases could be worked out by step by step methods, but the work would be laborious. Stringers and longerons all of constant cross-section is a case of no practical interest, because if the longerons can carry the load at one section, they can carry it at all sections, and diffusion is unnecessary. Stringers and longerons all tapered is the easiest case to solve and gives the most efficient structure; but the difficulty of manufacture is probably prohibitive. The intermediate case of the tapered longerons and stringers of constant section can be solved fairly easily and is probably the best practical arrangement.

Fan type structures and shear structures in which all the stringers are tapered can be designed to afford complete equalisation of the load applied to the monocoque in a finite length of diffusing structure; but no structure including stringers of constant section can afford complete equalisation except at infinite distance. Accordingly, Duncan (72) suggested the conception of "95 per cent. equalisation length," that is, the length of the diffusing structure at which the excess of the greatest load over its value at infinity is less than 5 per cent. Naturally the figure of 5 per cent. is arbitrary and any other ratio could be used in its place. Since the variation of the load in any stringer is approximately exponential, the variation of length for slight changes in the equalisation ratio is not very great. Experimental results (76, 77, 78) show that the theoretical predictions are at least qualitatively correct.

My colleague Smith has considered the effect of stiffening the sheet metal adjacent to the longeron carrying the concentrated load (72). The diagram Fig. 19 shows that a fairly considerable improvement can thus be effected at the expense of an increase of the equalisation length. The values of excess weights V_e and V_{es} on this diagram are expressed in arbitrary units and represent the estimated excess over the weight of the stringers alone of ordinary monocoque of the same length; but the comparison between values at different thickness ratios is unaffected by this consideration. The effect on the rate of transfer of the load is shown in Fig. 20 where the loads in the inner and outer stringers are shown for a number of different values of the thickness ratio. It should be noticed that if the inner web is made thicker than the outer the rate of transfer of load, particularly to the outer stringer, is *reduced*.

Concentrated loading is specially important in relation to wing structures. Apart from the loading due to flexural oscillations, which we hope may not be excited, the flexural loading on the wings is due to air forces on the upper and lower surfaces. The first effect of this loading is to set up shear stresses in the webs of the spars, and the shear stresses in the spar webs then impose differential tensile and compressive stresses on the spar flanges. These direct (bending) loads can then only be distributed across the whole surface of the wing by diffusion from

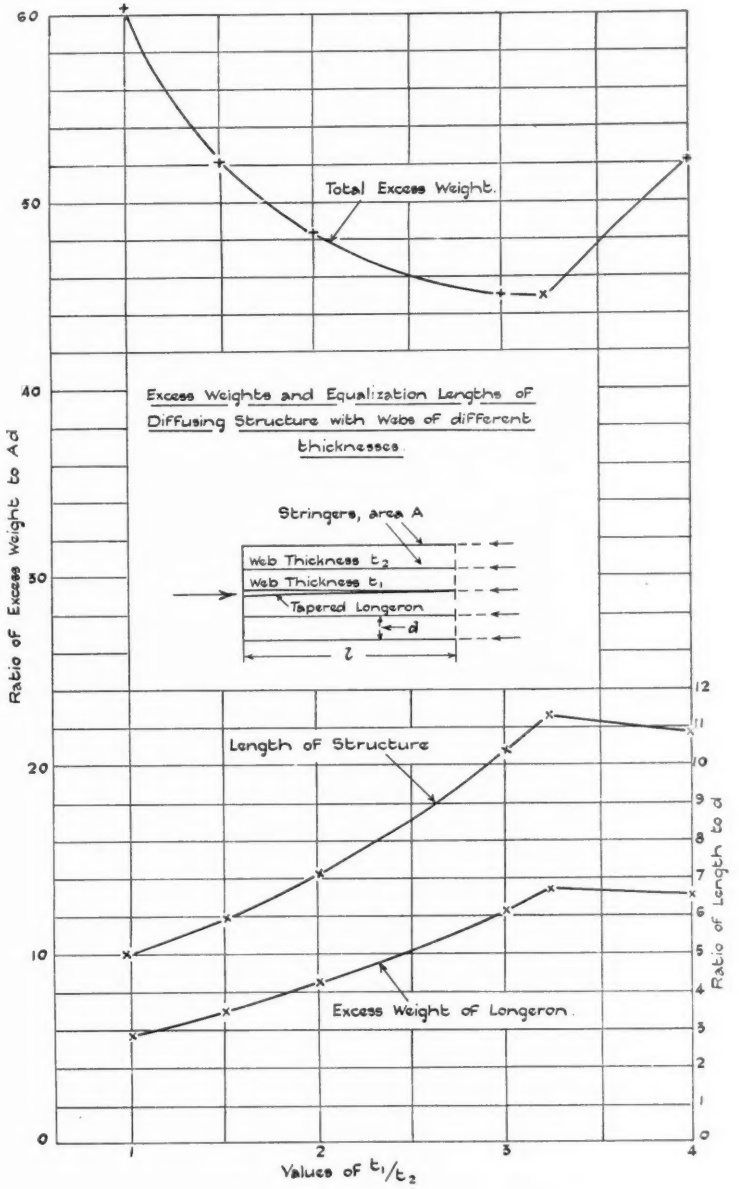


FIG. 19.

Effect of varying web thickness on excess weight of diffusing structure.

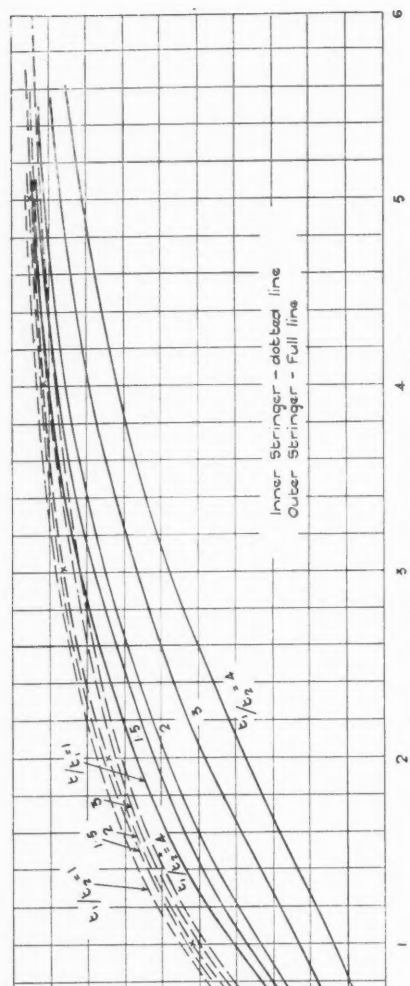


FIG. 20.

Effect of varying web thickness on rate of transfer of loads.

the actual spar webs. In this respect a multi-spar wing would obviously be more efficient; but for torsional strength and stiffness it is more advantageous to concentrate all the webs at the outer walls of the box, so that the two-spar or single box type of wing may be preferred. If the root fixing of the wing consists of four point attachments at the spar flanges, the loads previously distributed into the wing have again to be concentrated at the root. In a very short structure, this condition might render diffusion unprofitable; but in practical wing cases it appears that diffusion will always enable the spar flanges to be appreciably reduced in section.

7. Conclusion.

I had originally intended to add to this paper an appendix summarising the quantitative design data which could be regarded as well established; but the excellent summary on these lines prepared by Heck and Ebner which has already been reproduced in the Society's proceedings renders such an appendix unnecessary. In the preparation of this paper I have constantly referred to Heck and Ebner's summary, and I have concentrated my attention on those aspects of stress analysis where the established technique of design appears to me inadequate or capable of improvement. The references which I have noted have been chosen mainly in illustration of my general arguments and the list is not intended to be exhaustive. The most important, in fact the only important, particular in which I consider the data given by Heck and Ebner to be misleading is with regard to the calculation of the stress at which a stringer attached to thin sheet may be expected to buckle. My reasons for this opinion I have already fully explained; but I do suggest that considerable further research, particularly on curved constructions, is necessary before definite conclusions on this point can be reached. At the same time the full value of such research will only be realised if the actual stress is determined by appropriate strain measurements.

Finally, I wish to express my thanks to the Director of the National Physical Laboratory for permission to read this paper, to the Air Ministry for permission to refer to work carried out at the Royal Aircraft Establishment, and to the Aeronautical Research Committee for permission to make use of certain results as yet unpublished.

Appendix.

The Buckling of a Supported Strut.

Introduction.

The problem of the stability of thin walled tubes and curved panels under axial end load has been investigated both theoretically and experimentally by many different workers; but a considerable discrepancy between the theoretical and experimental results remains unexplained. The experimental results (*cf.*, *e.g.*, Fig. 4 of the paper for stress-strain diagram, reference 41, for form of buckle) show that up to the buckling load the curved sheet remains effectively cylindrical, but that instantaneously upon buckling, a large inward buckle of very characteristic lozenge shape is produced, while the load falls, and the strain increases considerably. Now the existing theory (2) is based upon consideration of small deflections and can refer only to the actual point at which deflection of the sheet out of the cylindrical form begins, so that the theory does not afford any indication of the behaviour after buckling. Nevertheless, there is nothing in the theoretical analysis to suggest that buckling may be accompanied by a fall of load, and by comparison with other apparently similar cases (*e.g.*, the flat panel) no such fall would be expected. Moreover, the experimental form of buckle, which is quite characteristic, is entirely different from the form suggested by the theory, and whilst the experimental values of the buckling stress vary

between very wide limits, the average value is little more than half the theoretical value (41, 42). After reviewing the leading characteristics of actual tests on tubes, L. H. Donnell (36) proposed a new theory based on the conception of gradual development of the buckled form from initial irregularities, and by this means he was able partially to reconcile the experimental with the theoretical results. On the other hand, for several reasons this explanation does not seem wholly satisfactory. In the first place the initial departures from the cylindrical form, which it is necessary to postulate, are so large that, even if they may be " suppressed " or hidden by the presence of initial stress, it seems most unlikely that they would pass unnoticed. Secondly, the experimental load-deformation curves give no hint of any gradual development of a buckled form, whereas, in other cases (18), the beginning of buckling is usually more clearly shown by the apparent change of stiffness in the stress-strain diagram than by actual observation of the deflection. Thirdly, the very sudden occurrence of buckling is scarcely consistent with gradual development of the buckled form, unless it were possible to establish the existence of some limit of depth of buckle beyond which the buckled form might become self-generating.

Apart from the variations in the actual values of the buckling stress, the experimental results appear to be extraordinarily consistent. It, therefore, appeared worth while to reconsider the theory and to determine what type of mechanism would be necessary to reconcile the theoretical with the experimental results.

When buckling is accompanied by a distinct fall of load, there is a strong presumption that the unbuckled form may for some time previously have been only metastable. This possibility was recognised at the time the tests described in reference 31 were carried out, but no clear indication of the existence of such a condition was obtained. On the other hand, the existence of a metastable range would explain the wide variations between the experimental values of the buckling stress. A search was therefore made for a type of mechanism which might be expected to reproduce the experimental characteristics of the buckling of curved panels, including the possibility of a metastable range of stability in the unbuckled form immediately prior to buckling.

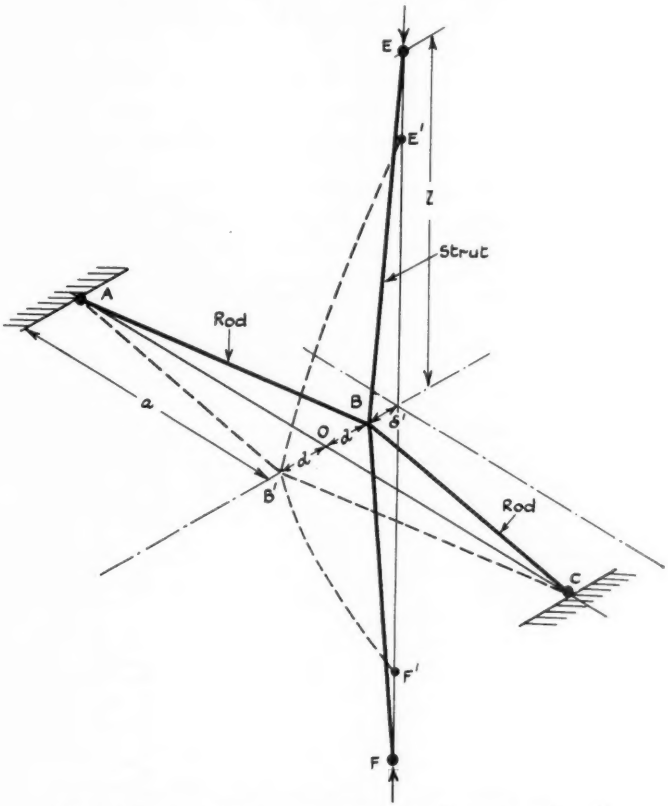
All the characteristics of the buckling of curved panels suggest strongly that direct stress in the circumferential direction has an important effect. In particular, this consideration would explain the preference for inward buckling and the rapid development of deep buckles. For this reason, it was considered worth while to explore the effect of cross compression of this type; but in view of the complexity of the actual panel problem, the analysis has so far been restricted to the case of a single strut supported laterally in a manner generally representative of the lateral support afforded to longitudinal fibres of the curved panel.

Statement of Strut Problem.

The problem here investigated is that of the stability under end load of a single strut supported at its centre by two rods lying in a plane perpendicular to the axis of the strut and mutually inclined at an angle slightly less than 180°. The rods are assumed to be pin-jointed at either end and their outer ends are assumed to bear against immovable anchorages. The isometric view shown in Fig. 1 illustrates the manner in which this system may behave. It is clear that, even if the strut is unloaded, if the rods are stiff enough in relation to the strut, in addition to the stable configuration ABC when the strut is unbent and the rods uncompressed, a second stable configuration $AB'C$, in which B' lies on the opposite side of AC but nearer to AC than B, may also be possible; for the bent form of the strut may in that position be maintained by compressive loads in the rods. If the rods are relatively less stiff, they may be incapable by themselves of maintaining the buckled form; but at least they must reduce the end load

necessary. Thus the end load required to maintain the configuration $AB'C$ is certainly less than that required to cause small deflection from the configuration ABC, so that a fall of load at buckling and a rapid development of the buckled form is to be expected. Fig. 1, however, does not suggest how the system may be expected to pass through all the configurations from ABC to AOC (O being the mid-point of AC), nor is it immediately obvious that the strut must buckle thus inwards rather than outwards.

In order to show the nature of the effect of initial curvature of the strut, the analysis developed below deals with a strut kinked at its centre B, so that its two halves make equal and opposite angles slightly different from 90° with the plane of the side rods. The case of the straight strut (when the two halves are in line) is dealt with as a special case of this more general problem.



Dotted lines suggest configuration of strut and rods when deflection at B is 2 d (r=2).

FIG 1.

Isometric view of supported strut (kinked at its centre).

ANALYSIS OF STRUT PROBLEM.

Let

l=length of the strut.

l'=length of each rod=$(a^2+d^2)^{\frac{1}{2}}$, where

$2a$ = distance between fixed anchorages of rods.

d = offset of rods at strut ($=OB$ in Fig. 1) from the line joining their outer ends.

E = Young's modulus, 1 = area of section, $I = Ak^2$ = modulus of section } of the strut.

E' = Young's modulus, A' = area of section } of each rod.

x = distance measured from one end of the strut.

e = overall strain of strut, so that its two ends approach each other by the distance le.

$\Sigma C_n' \sin(n\pi x/l)$ = initial form of the strut.

$\Sigma C_n \sin(n\pi x/l)$ = buckled form of the strut.

$\delta = (C_1 - C_3 + C_5 - \ldots, \text{ etc.}) - \delta_1' =$ deflection at centre of strut.

$\delta' = (C_1' - C_3' + C_5' - \ldots) =$ initial deflection at centre of strut,

where $C_{2n+1}' = \{(-1)^n/(2n+1)^2\}(8\delta'/\pi^2)$.

The flexural energy stored in the strut $= (\pi^4 EI/4l^3)\Sigma n^4 (C_n - C_n')^2$.

The direct stress energy stored in the strut

$$= \tfrac{1}{2} EAl \{ e - (\pi^2/4l^2)(\Sigma n^2 C_n^2 - \Sigma n^2 C_n'^2) \}^2.$$

The direct stress energy stored in the (two) rods

$$= E'A'(a^2+d^2)^{\frac{1}{2}} \{ 1 - \sqrt{[\{a^2 + (d-\delta)^2\}/(a^2+d^2)]} \}^2.$$

Differentiating the total energy with respect to le gives the end load P. Differentiating with respect to each C in turn and equating to zero, sufficient equations are obtained to eliminate all the C's, leaving one relation between P and e; but owing to the complexity of the problem this relation cannot conveniently be expressed explicitly. Differentiation with respect to le gives

$$P = EA \{ e - (\pi^2/4l^2)(\Sigma n^2 C_n^2 - \Sigma n^2 C_n'^2) \}.$$

This relation is expressed more conveniently in the form

$$f/f_0 = \rho^2 = P/EAe_0 = e/e_0 - (1/4k^2)(\Sigma n^2 C_n^2 - \Sigma n^2 C_n'^2),$$

where $e_0 = \pi^2 k^2/l^2 =$ buckling strain of unsupported (straight) strut of length l, and $f/f_0 = \rho^2 =$ ratio of applied load to buckling load of unsupported straight strut.

Differentiation with respect to C_{2n} gives

$$(\pi^4 EI/4l^3)(2n)^4 (C_{2n} - C_{2n}') - (\pi^2 EA/4l)(2n)^2 (\pi^2 k^2/l^2)\rho^2 C_{2n} = 0.$$

Hence $C_{2n}/C_{2n}' = (2n)^2/\{(2n)^2 - \rho^2\}$ simply, and, if $C_{2n}' = 0$ and $\rho < 2$, as we shall assume, $C_{2n} = 0$ for all values of n.

Differentiation with respect to C_{2n-1} gives

$$(2n+1)^4 (C_{2n+1} - C_{2n-1}') - (2n+1)^2 \rho^2 C_{2n+1} + (-1)^n (32/\pi^2) \times Md (R^2+1)^{3/2} (1-r) [\{R^2 + (1-r)^2\}^{-\frac{1}{2}} - \{R^2+1\}^{-\frac{1}{2}}],$$

where

$$M = (1/8\pi^2)(E'A'l^3/EAl'^3)(d^2/k^2), \quad R = a/d \text{ and } r = \delta/d.$$

Hence

$$C_{2n+1} = \{(2n+1)^2 C_{2n+1}'\}/\{(2n+1)^2 - \rho^2\} - \{(-1)^n X dM\}/[(2n+1)^2\{(2n+1)^2 - \rho^2\}]$$

where

$$X = (32/\pi^2)(R^2+1)^{3/2}(1-r)[\{R^2+(1-r)^2\}^{-\frac{1}{2}} - \{R^2+1\}^{-\frac{1}{2}}].$$

Now

$$\begin{aligned} r = \delta/d &= (1/d)(C_1 - C_3 + C_5 - \ldots) - (1/d)(C_1' - C_3' + C_5' - \ldots) \\ &= (1/d)\Sigma\{(-1)^n \rho^2 C_{2n+1}'\}/\{(2n+1)^2 - \rho^2\} \\ &\quad - XM\Sigma\, 1/[(2n+1)^2\{(2n+1)^2 - \rho^2\}] \\ &= \{(8\delta'\rho^2)/(\pi^2 d) - XM\}\Sigma\, 1/[(2n+1)^2\{(2n+1)^2 - \rho^2\}] \\ &= \{(8\delta'\rho^2)/(\pi^2 d) - XM\}(\pi^2/8\rho^2)\{(2/\pi\rho)\tan(\pi\rho/2) - 1\}. \end{aligned}$$

Also

$$\Sigma\,(2n+1)^2\,C'^2_{2n+1}-\Sigma\,(2n+1)^2\,C'^2_{2n+1}$$
$$=\Sigma\,\{\,[(2n+1)^3\,C'_{2n+1}]/[(2n+1)^2-\rho^2]$$
$$-[(-1)^n\,XdM]/[(2n+1)\,\{\,(2n+1)^2-\rho^2\,\}\,]\,\}^2-\Sigma\,(2n+1)^2\,C'^2_{2n+1}$$
$$=\Sigma\,\{\,(8\,\delta'/\pi^2)\,[2n+1]/[(2n+1)^2-\rho^2]-XdM/[(2n+1)\,\{\,(2n+1)^2-\rho^2\,\}\,]\,\}^2$$
$$-(64\,\delta'^2/\pi^4)\,\Sigma\,1/(2n+1)^2$$
$$=(64\,\delta'^2/\pi^4)\,\{\,\Sigma\,(2n+1)^2/\{\,(2n+1)^2-\rho^2\,\}^2-\Sigma\,1/(2n+1)^2\,\}-16\,\delta'XdM/\pi^2$$
$$\times\Sigma\,1/\{\,(2n+1)^2-\rho^2\,\}^2+X^2d^2M^2\,\Sigma\,1/[(2n+1)^2\,\{\,(2n+1)^2-\rho^2\,\}^2]$$
$$=\{\,X^2d^2M^2-(64\,\rho^4\delta'^2)/(\pi^4)\,\}\,\Sigma\,1/(2n+1)^2\,\{\,(2n+1)^2-\rho^2\,\}^2$$
$$+(16\,\delta'/\pi^2)\,\{\,(8\,\rho^2\delta')/(\pi^2)-XdM\,\}\,\Sigma\,1/\{\,(2n+1)^2-\rho^2\,\}^2$$
$$=\{\,X^2d^2M^2-(64\,\rho^4\delta'^2)/(\pi^4)\,\}\,(\pi^2/16\,\rho^4)\,\{\,3+\tan^2(\pi\rho/2)-(6/\pi\rho)\tan(\pi\rho/2)\,\}$$
$$+(16\,\delta'/\pi^2)\,\{\,(8\,\rho^2\delta')/(\pi^2)-XdM\,\}\,(\pi^2/16\,\rho^2)\,\{\,1-(4/\pi\rho)\tan(\pi\rho/2)+\tan^2(\pi\rho/2)\,\}.$$

Hence

$$XM/r=(8\,\delta'\rho^2)/(\pi^2dr)-8\,\rho^2/\pi^2\,\{\,(2/\pi\rho)\tan(\pi\rho/2)-1\,\}\quad.\qquad(1)$$

or

$$M\,(R^2+1)^{3/2}\,\{\,(1-r)/r\,\}\,[\,\{\,R^2+(1-r)^2\,\}^{-\frac{1}{2}}-\{\,R^2+1\,\}^{-\frac{1}{2}}]$$
$$=(\rho^2\delta'/4\,dr)-\rho^2/4\,\{\,(2/\pi\rho)\tan(\pi\rho/2)-1\,\}\quad.\qquad(1a)$$

or approximately

$$M\,(1-r)\,(1-r/2)\,[1+(3/4)\,\{\,r\,(2-r)/(R^2+1)$$
$$+(5/8)\,\{\,r^2\,(2-r)^2/(R^2+1)^2\,\}+\ldots]$$
$$=(\rho^2\delta'/4\,dr)-\rho^2/4\,\{\,(2/\pi\rho)\tan\pi\rho/2)-1\,\}\quad.\quad.\quad.\qquad(1b)$$

and

$$e/e_o=\rho^2+(1/4\,k^2)\,\{\,\Sigma\,(2n+1)^2\,C'^2_{2n-1}-\Sigma\,(2n+1)^2\,C'^2_{2n+1}\,\}$$
$$=\rho^2+(1/4\,k^2)\,\{\,X^2d^2M^2-(64\,\rho^4\delta'^2)/(\pi^4)\,\}\,(\pi^2/16\,\rho^4)\,\{\,3+\tan^2(\pi\rho/2)$$
$$-(6/\pi\rho)\tan(\pi\rho/2)\,\}+(1/4\,k^2)\,(\delta'/\rho^2)\,\{\,(8\,\rho^2\delta')/(\pi^2)$$
$$-XdM\,\}\,\{\,1+\tan^2(\pi\rho/2)-(4/\pi\rho)\tan(\pi\rho/2)\,\}.$$

Substituting for XM from (1)

$$e/e_o=\rho^2+(d^2/4\,k^2)\,(\pi^2/16\,\rho^4)\,\{\,[(8\,\delta'\rho^2)/(\pi^2d)-8\,\rho^2r/\pi^2\,\{\,(2/\pi\rho)\tan(\pi\rho/2)-1\,\}\,]^2$$
$$-(64\,\rho^4\delta'^2)/(\pi^4d^2)\,\}\,\{\,3+\tan^2(\pi\rho/2)-(6/\pi\rho)\tan(\pi\rho/2)\,\}$$
$$+(d^2/4\,k^2)\,(1/\rho^2)\,(\delta'/d)\,\{\,(8\,\rho^2/\pi^2)\,(\delta'/d)-(8\,\rho^2/\pi^2)\,(\delta'/d)$$
$$+8\,\rho^2r/\pi^2\,[(2/\pi\rho)\tan(\pi\rho/2)-1\,]\,\}\times[1+\tan^2(\pi\rho/2)-(4/\pi\rho)\tan(\pi\rho/2)].$$

After some reduction this relation can be expressed in the form:—

$$e/e_o=\rho^2+(d^2/k^2)\,(r^2/\pi^2)\,[\,\{\,(2/\pi\rho)-\cot(\pi\rho/2)\,\}^{-2}$$
$$+3\,\{\,1-(2/\pi\rho)\tan(\pi\rho/2)\,\}^{-1}+(4\,\delta'/rd)\,].*\quad.\quad.\quad.\qquad(2)$$

SPECIAL CASE OF THE STRAIGHT STRUT ($\delta'=0$).

If ρ is limited to values less than 2, the greatest (negative) value of the R.H.S. of equation (1*b*) is 1, so that for buckling in a mode for which r is not zero to be possible, M must be less than 1. The values of the functions

$$(\rho^2/4)\,\{\,(2/\pi\rho)\tan(\pi\rho/2)-1\,\}^{-1}$$

and

$$[\,\{\,(2/\pi\rho)-\cot(\pi\rho/2)\,\}^{-2}+3\,\{\,1-(2/\pi\rho)\tan(\pi\rho/2)\,\}^{-1}]$$

are shown plotted against values of ρ between 0 and 2 in Fig. 2. At $\rho=0$, the value of the former is $3/\pi^2$ and it decreases steadily through zero at $\rho=1$ to -1 at $\rho=2$. When r is very small the value of this function must be $-M$, so that buckling will commence at some value of ρ between 1 and 2. When $r=1$ or 2, $\rho=1$ for all values of M; for $\rho=1$, equation (2) becomes

$$e/e_o=1+(r^2/4)\,(d^2/k^2),$$

* It is interesting to note that the term in δ' in this expression for e/e_o is exactly that which would be deduced by considering merely the geometrical effect of superposing the deflection δ on the initial deflection δ'.

so that the stress-strain curve after buckling always passes through the two points

$$\rho^2 = 1, \quad e/e_0 = 1 + (d^2/4k^2), \text{ and } 1 + (d^2/k^2).$$

In addition equation (2) shows that immediately after buckling when r is still very small $d(e/e_0)/d\rho^2 = 1$, so that the curve relating e/e_0 to ρ^2 after buckling touches the elastic line at the buckling stress. Two series of stress-strain curves, calculated on the assumption that $r(2-r)/(R^2+1)$ is negligible in comparison with unity, are shown in Fig. 5 of the paper (various values of d/k with M constant) and in Fig. 3 of this appendix (various values of M with d/k constant).

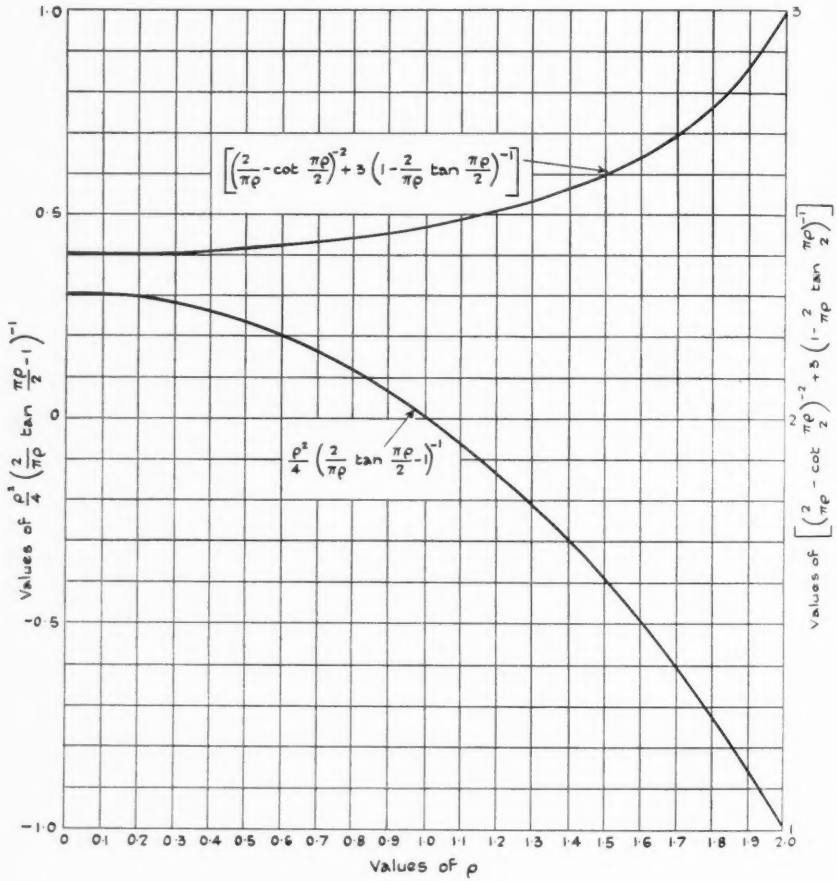


FIG. 2.

Buckling of a supported strut. Load functions.

It should be remarked that $M\ \{ = (E'A'l^3)/E.1\,(2\,l')^3 \,.\, (d^2/\pi^2k^2)\}$ is the product of the ratio of the rigidity of a rod to the rigidity of half the strut and the offset ratio d^2/π^2k^2; the value of M therefore varies with d^2/k^2 unless the rigidity ratio is also altered. On the other hand, the buckling stress depends on M only, so that it seems preferable to regard M as the factor of support, rather than to use the rigidity ratio alone.

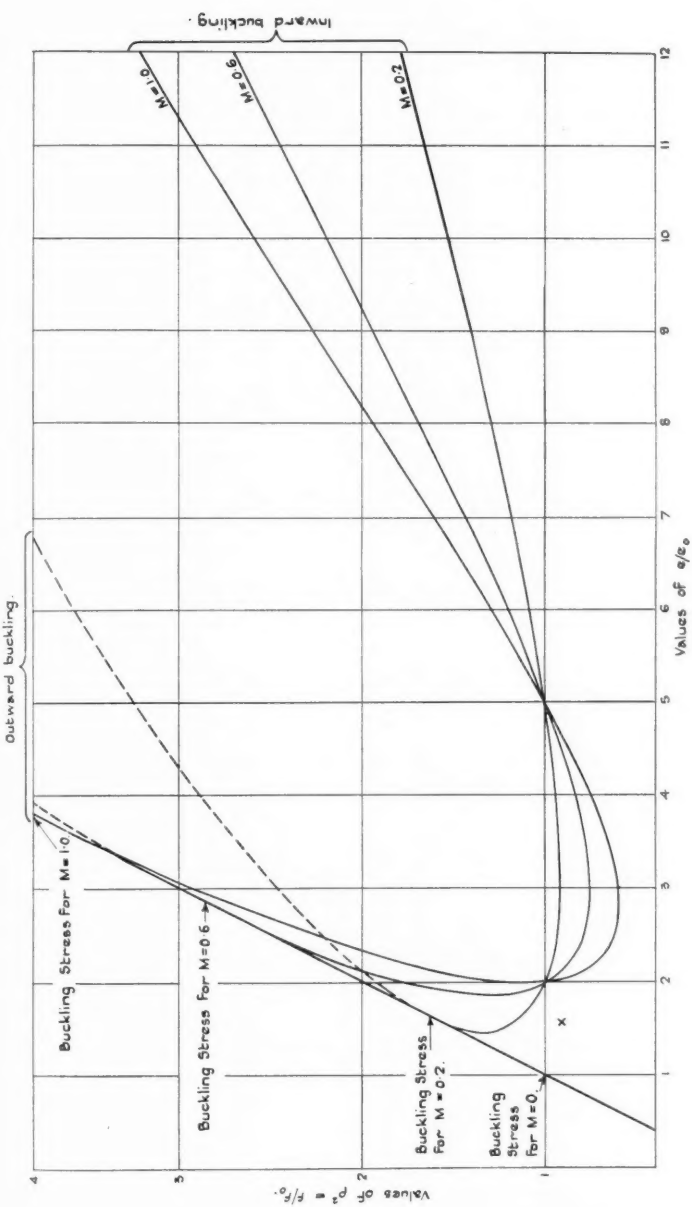


Fig. 3.

Buckling of a supported strut theoretical stress-strain curves. For various rigidities of support, $d/k = 2$.

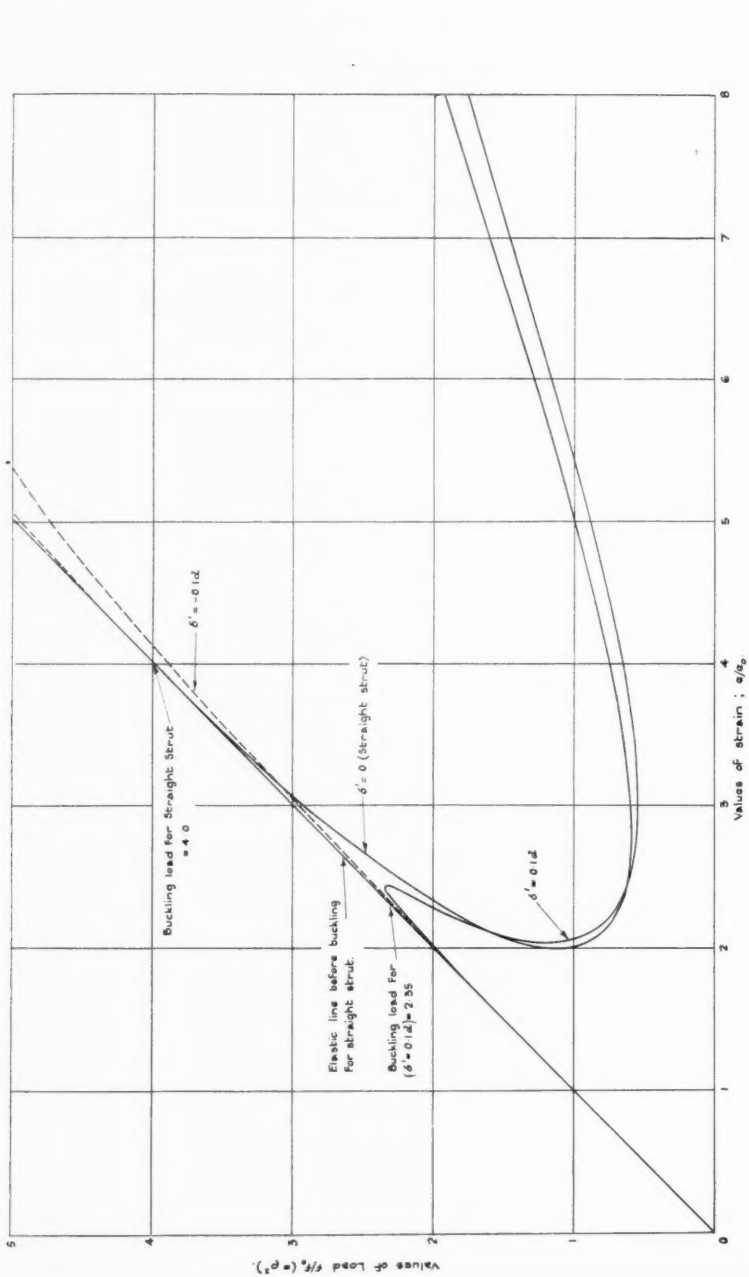

Values of load ϕ/ϕ_e ($= \rho^2$).
Values of strain ; e/e_0
$\delta' = 0.1d$
$\delta' = 0$ (Straight strut)
$\delta' = 0.1d$
Buckling load for Straight Strut $= 4.0$
Elastic line before buckling for straight strut
Buckling load for $(\delta' = 0.1d) = 2.95$

FIG. 4.

Buckling of a supported strut-effect of initial deflection of the strut $(M = 1,\ d/k = 2)$.

EFFECT OF INITIAL KINK IN THE STRUT.

It is apparent from the form of equation (1*b*) that, if $\delta' \neq 0$, r must increase steadily with ρ^2. This result would of course be expected, for the end load on the bent strut must set up a side thrust at the kink.

Stress-strain curves for one pair of values of M and d/k and $\delta'/d = \pm 0.1$ are shown in Fig. 4. The chief effect of a small positive value of δ' is to round off the cusp of the stress-strain diagram appropriate to $\delta' = 0$; the value of the

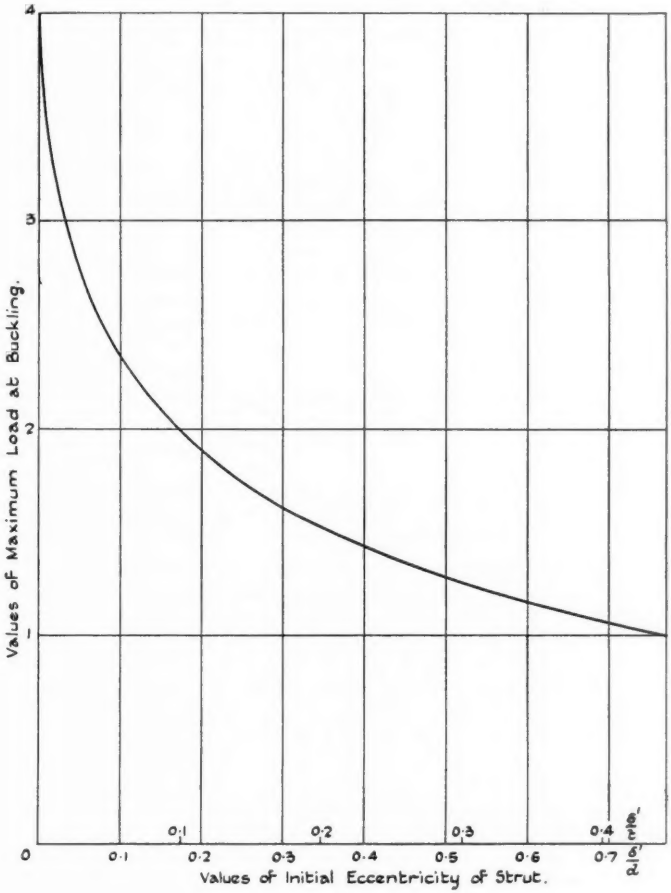


FIG. 5.

Effect of initial eccentricity of strut on maximum load at buckling.
$M = 1$, $d/k = 2$.

maximum load is thereby greatly reduced and is moreover rendered extremely sensitive to small changes in the value of δ'. This sensitivity to slight changes in the value of δ' is illustrated in Fig. 5, where the value of the maximum load at buckling has been plotted against values of δ'/d, again for the case $M = 1$, $d/k = 2$. The second scale of abscissæ on this diagram gives the values of δ'/t

for a strut of rectangular section of thickness t. It will be seen that the values of δ'/t necessary to cause very marked reductions of buckling load are extremely small. Larger positive values of δ' cause the differences from the curve for $\delta'=0$ to be accentuated; but the general similarity remains well marked up to quite high values of δ'.

Negative values of δ' cause the strut to begin to buckle outwards, in the sense in which the side rods are extended. This process once begun can never cease, so that no instability of the strut* can ever occur. The reason for this difference between the effects of positive and negative values of δ' is most easily seen by putting equation (1b) in the form

$$Mr(1-r)(1-r/2)=(\rho^2\delta'/4d)-\rho^2 r/4\{(2/\pi\rho)\tan(\pi\rho/2)-1\},$$

and by plotting the two sides of this equation separately against values of r on the same diagram. For some range of values of ρ from a certain minimum depending on the value of M up to $\rho=2$, the slope of the line representing the R.H.S. exceeds the slope of the cubic at $r=0$. Nevertheless, the slope of the line is never infinite, so that the lowest intersection with the cubic at a positive value of r of the steepest line starting from a negative value of δ' cannot be less than a certain finite minimum. Values of r between this positive minimum and zero are impossible, so that the strut cannot pass through the configurations corresponding to these intermediate values.

The stress-strain curve after buckling for $\delta'=0$ consists of a single curve which touches the elastic line $\rho^2=e/e_0$. The upper branch of this curve corresponds to negative values of r, that is to outward buckling of the strut, and the lower branch to positive values of r, that is to inward buckling. The stress-strain curve after buckling when δ' is positive is a modification of the lower branch and the stress-strain curve after buckling when δ' is negative is a modification of the upper branch.

Conclusions.

The curves shown in Figs. 3 and 4 reproduce all the characteristics of stress-strain curves obtained by tests on curved panels remarkably exactly. The points of resemblance may be summarised as follows:—

(*a*) The attainment of the true buckling load is very largely dependent on the perfection of form of the strut. If the strut is slightly bowed inwards, the buckling load is considerably reduced, and the actual value of the maximum load is very sensitive to slight differences in initial eccentricity. This provides an explanation of the wide variations between the results of individual tests which is even more satisfactory than would be afforded by a true metastable range.

(*b*) Provided the initial eccentricity is zero or positive, a definite but limited fall of load occurs after buckling, whilst a deep buckle is formed instantaneously (the lowest point of the curves shown in Figs. 3 and 4 corresponds to an inward deflection of about $3/2\,d$).

(*c*) As the strain is increased still further, the load commences again to rise; but at much greater strains with a high value of M, the stress-strain curve becomes concave to the strain axis. This phenomenon was noticed in the tests on curved panels, but at that time it was thought that the effect was probably due to elastic failure.

(*d*) The qualitative comparison between the behaviour of a supported strut and that of a curved panel illustrated by Fig. 6 of the paper suggests that the explanation of the discrepancies between the theoretical and experimental results for curved panels may be sought along similar lines. It is interesting to note that the position of the buckling load for a flat panel of the same elevation as the curved panel, to which Fig. 6 of the paper refers, in relation to the true stress-

* That is instability of the strut as a whole. The two halves will still, of course, buckle at $\rho^2=4$.

strain curve there suggested is very similar to the position of the line $f/f_0=\rho^2=1$ in relation to the curves of Figs. 3 and 4.

(*e*) The conclusion that even a very slight initial eccentricity of the strut outward must entirely prevent instability in one half wave suggests valuable practical applications. By analogy between the supported strut and the curved panel it might appear that, if the tube or panel were made slightly barrel shaped, local buckling could be entirely prevented; but this conclusion can scarcely be accepted without more detailed examination.

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IX. Stiffening of Holes Cut in Monocoque Structure.

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66. C. Gurney. An Analysis of the Stresses in a Flat Plate with a Reinforced Circular Hole under Edge Forces. A.R.C., R. & M. No. 1834.
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X. Diffusion of Concentrated Loads into Monocoque Structure.

70. H. L. Cox, H. E. Smith and C. G. Conway. Diffusion of Concentrated Loads into Monocoque Structures. A.R.C., R. & M. No. 1780.
71. W. J. Duncan. Diffusion of Load in Certain Sheet-Stringer Combinations. A.R.C., R. & M. No. 1825.
72. H. E. Smith. Diffusion of Load in Sheet-Stringer Combinations having a Tapered Centre Stringer. A.R.C., R. & M. No. 1862.
73. H. L. Cox. Diffusion of Concentrated Loads into Monocoque Structure. General Considerations with particular reference to Bending Load Distributions. A.R.C., R. & M. No. 1860.
74. H. F. Winny. The Distribution of Stress in Monocoque Wings. A.R.C., R. & M. No. 1756.
75. E. Reissner. On the Problem of Stress Distribution in Wide Flanged Box Beams. J. Aero. Sci., Vol. 5, p. 295.
76. B. B. C. Lovett and W. F. Rodee. Transfer of Stress from Main Beams to Intermediate Stiffeners in Metal Sheet covered Box Beams. J. Aero. Sci., Vol. 3, p. 426.
77. R. J. White and H. M. Autz. Tests on the Stress Distribution in Reinforced Panels. J. Aero. Sci., Vol. 3, p. 209.
78. E. Schapitz, H. Feller and H. Köller. Experimental and Analytical Investigation into the Bending of a Model Monocoque Wing. L.F.F. 15, p. 563.
79. P. Kuhn. Stress Analysis of Beams with Shear Deformation of the Flanges. N.A.C.A. Rep. No. 608.

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81. H. Ebner and H. Köller. Calculation of Load Distribution in Stiffened Cylindrical Shells. N.A.C.A. Techl. Mem. No. 866.
82. H. Ebner and H. Köller. On the Load Distribution in Longitudinally and Laterally Stiffened Shells. L.F.F. 15, p. 527.

XI. RIVETS.

83. W. L. Howland. Effect of Rivet Spacing on Stiffened Thin Sheet under Compression. J. Aero. Sci., Vol. 3, No. 12, p. 434.
84. A. Kromm. The Effect of Rivet Spacing on the Pressure Resistance of Reinforced Duralumin Shells. L.F.F. 14, No. 3, p. 116.
85. H. Portier. The Riveting of Thin Sheets in Aeronautical Construction. Pub. Sci. et Tech. du Min. de l'air. B.S.7, No. 87.

DISCUSSION.

The CHAIRMAN: He expressed congratulations to the author and admiration of the work which had gone to the making of the paper, which would probably go down to history as " Cox on Monocoques "!

The paper indicated that a tremendous amount of work had been done on thin sheet metal, and there was a very great deal of literature on the subject, represented by the excellent bibliography at the end of Mr. Cox's paper. It appeared to be essential that there should be a body of scientists and engineers devoting their time to analysing all that work critically, and presenting it to designers in the form of data sheets and the like, so that the industry should have the full benefit of the very valuable research work that was always proceeding. Otherwise, valuable facts might be lost in the depths of that gigantic literature. Papers like Mr. Cox's, and the well-known paper by Heck and Ebner, were of great value in that direction.

Commenting on Mr. Cox's exposition of the f_b and n method and the effective width method, he confessed, to his shame, that he had never used either; but it seemed to him that they must be basically much the same. Even if the effective width were not stated explicitly in Mr. Cox's method, it was there just the same. It seemed to him that it should be possible so to refine the application of the effective width method (perhaps by replacing the constant multiplier by one variable with load) that it could be used directly in a manner not dissimilar from that which had been explained by Mr. Cox for his own method.

Dr. W. D. DOUGLAS (*Fellow*): Whilst complimenting Mr. Cox on the simplicity with which he had presented a very complicated subject, he said that he had skimmed over one point which some people might find difficulty in following. It concerned the buckling load of a combination of a stringer and a curved panel, it having been stated that they would both buckle in the same form; presumably that meant that the centre line of the buckled panel and the centre line of the buckled strut would be of the same shape. If that were so, he could appreciate that the buckling load of the combination would be the sum of the loads which would be necessary to buckle the separate elements into that shape and length. But he could see no particular reason why they should interact on each other, *i.e.*, why the panel should then carry more load, and the strut less load, than before. He asked if Mr. Cox would make that point clearer.

With regard to the experimental curves for the buckling of a curved panel, in Figs. 4 and 6, it was very noticeable that when the strain was increased after the panel had buckled, the lines proceeded upwards in more or less linear fashion, which one could extrapolate back to zero. But in the case of the theoretical curves in Fig. 5 one could not extrapolate back to zero. He wondered whether there was any significance in that.

The method of starting at the middle and using the angle 2θ to indicate the proportion of the periphery of the circular tube over which buckling had occurred was very convenient. But the author had stated that over the portion included in the angle of 2θ he had assumed the buckling stress. Was that a constant

stress? Was it assumed that the panel carried a definite constant stress after buckling, or was it again a stress which would be dependent on the strain at each portion of the periphery inside the angle 2θ? It was also stated that in order to allow for the effect of the secondary buckling of the skin between ribs, and to secure agreement with one or two experimental results, he could use the fixation factor of 1.7 for the sheet. What was the degree of constancy of that factor? Was the 1.7 a reasonable factor to use for normal close riveted construction, or was it greatly influenced by the ratio of rivet pitch to thickness of sheet?

The paper had given a very valuable yardstick for measuring the accuracy of the design of stressed skin constructions which were not complicated by holes or stress concentrations. It would be of great value if the test could be applied and the results published in cases where failure had occurred in such comparatively simple forms of stressed skin construction.

Mr. A. E. RUSSELL (*Fellow*): He believed the effective width method was capable of giving accurate results. Some three or four years ago he had analysed the same tests on the cylinders by a modification of the usual strip method, and the stresses for the first two cylinders were 10.7 and 11.3 tons per square inch; the stresses on the corresponding panels were 12.7 and 12.2 tons per square inch. These figures closely agree with the values given in the paper. The analyses of the remaining available data gave approximately the same results. When all these results were plotted on the equivalent strut curve the values lay above the curve.

Subsequently a series of tests was carried out on panels with extruded stringers having the same section constants and still higher stresses were obtained.

He found it hard to reconcile these results with Mr. Cox's statement that the strut value represented the optimum value for compression.

He also said that he was dissatisfied with all existing methods known to him for the design of the ring or hoop members and asked if there was any likelihood of a reliable method forthcoming in the near future.

Dr. A. P. THURSTON (*Fellow*): He complimented the author upon the manner in which he had combined practical tests with theoretical considerations; he also paid tribute to the valuable contributions made by the National Physical Laboratory and the Royal Aircraft Establishment to the theory of the design of aircraft structures, and to the manner in which Mr. Cox was carrying on the tradition.

Aircraft in action have so many stresses variable both in amount and direction that each part should be examined for stresses in varying directions.

Asking for information concerning cross buckling and the best line on which to place the anti-buckling devices, he wondered whether the author had made experiments to test the strength of panels under loads inclined to the main axis. In early experiments on spars it had been common practice to place the corrugations vertically; but he had found them much more efficient when placed longitudinally, and in certain cases when inclined over a portion.

Another matter on which he asked for information was that of testing panels which had been damaged locally or from which portions had been removed, in order to estimate the strength of panel structures when portions had been shot away. The parts of the structures of aircraft made during the last war were so made that if any part were shot away, the pilot had always a " second string to his fiddle " to enable him to get home. But the part which had puzzled Dr. Thurston at that time was the top front spar. The metal construction, however, provided two or more than two strings to the fiddle.

He also asked what variation in the load factor the author had made to the various parts of the structure to obtain the utmost efficiency because some parts of the structure were more liable to damage and to stress than were others. Again, what allowance did the author make for combined bending moments and torsion of the body? In other words, what assumptions did he make in order to arrive at the stress analysis?

Asking for further particulars of the author's assumptions concerning the diffusion of loads which would become concentrated if precautions were not taken to prevent it, and whether the structure as a whole was made to assist in carrying the load, he referred to certain loaded wings as an example of what could be done in that direction. At first, when the wings were under stress, the deflection became such that the central portion had taken more than its proper share of the load. But the design was modified so that the yielding of that portion resulted in part of the load being transferred to other portions, so that it was decreased at the first portion and more or less equalised throughout the structure.

Mr. I. J. GERARD (*Fellow*): He was particularly interested to note how closely the author's calculated stress values agreed with the experimentally derived values.

Commenting on the series of cylinders (4) referred to in the paper as having been tested in the course of the Air Ministry's research on monocoque construction, he said the author had not mentioned a third cylinder which was included in that series. In many ways it was the most interesting of the three, and it afforded a very good example of the mode of bowing taken up by stringers. In that connection, he referred to Fig. 14 in the paper, on the extreme right of which there was an example of a form of bowing, where there was a series of alternate inward and outward bowing with zero deflection at each ring. During test the third cylinder had first appeared to develop bowing of that type, but was ultimately prevented from so doing, as bowing outwards would have involved stretch of the skin circumferentially. He had found that the ultimate strength of a panel with encastred ends and of length equal to the pitch of the rings was in good agreement with the failing stress of a complete cylinder.

Dealing with the point raised by Dr. Thurston concerning the concentration of stresses at certain points in structures, he agreed that, although much work had been done on that subject, such concentrations in a ductile material merely gave rise to a little local stretch, and so the menace of the failure of the structure, due to the high calculated stresses disappeared. The continued use of ductile materials in lightweight highly stressed structures would therefore probably be necessary. In that connection, the shear strength of rivets was important. There seemed to be less ultimate distortion in shear in a rivet than there was stretch in a simple tension member, so that in designing riveted structures of any kind it seemed advisable to err on the lavish side in regard to the number of rivets used. He asked for the author's comments on that matter.

However one calculated the stresses in a structure of the types dealt with in the paper, the total strength rested finally on the strength of the stringers. In that connection, the research work (58), carried out by the Air Ministry, in co-operation with the Aeronautical Research Committee, had pointed to the use of stringers which must be stable, not merely in bending, but also in torsion. The tubular stringers mentioned in one of the illustrations in the paper gave notably better results than stringers of open section. Whenever a composite structure of that kind was tested, he said, the skin began to wrinkle first, and in some cases that wrinkling passed into the stringer, so causing the collapse of the stringer, which meant the collapse of the whole structure. He asked if the author had come across any theoretical work on the interaction between the skin and the stringers.

The extruded section stringer mentioned by Mr. Russell was a good second to the tubular stringer, and according to some of his tests it was, for a given weight, about 85 per cent. as strong as the corresponding tubular stringer. It had been shown that in the design of a complete structure incorporating tubular stringers the efficiency of the stringer could be developed to such an extent that compression failures could be avoided altogether. In this particular development of monocoque construction this country led the world.

Mr. H. A. FRANCIS (*Associate Fellow*): He commented that the pitch of the rivets in the stringers of a comparatively simple monocoque was perhaps one of the most

important factors, and it had not been treated in the academic researches because it had been considered rather a nuisance. He believed that often premature failures were due in part to rivet heads popping off at awkward moments, and it seemed that the matter was not sufficiently covered in research.

He endorsed heartily the remarks of Dr. Douglas about analysing tests which had been made on very unorthodox types of monocoque structures, because designers were up against difficulties continually with regard to such structures. The orthodox monocoque did not give rise to difficulties in design, thanks to the researches which had been carried out; but there was a great need for research on concentrated loads and cut-aways. He hoped that in the future there would be a very comprehensive analysis of the *ad hoc* structural tests carried out at Farnborough and elsewhere.

Dr. S. C. Redshaw (*Associate Fellow*): In discussing the curved panel, he said the author had rightly pointed out that experimental results did not agree with theory, experiments giving values of about half, or even less than half, the theoretical values. That matter had worried him for a long time, and he had tried in various ways to make an analysis which would bring the theoretical results nearer to the experimental; but he had not yet discovered where the trouble lay. It was curious because the curved panel analysis could in the limiting case be brought to the flat plate analysis, in which case the agreement with experiment was very good; but the moment curvature was introduced, the results were right off the map. He was not sure that the author's explanation of the faulty strut altogether explained that, and he would like to see the matter cleared up.

Another rather serious matter was that in all the work they were relying entirely on either theoretical calculations or on experimental tests which were carried out with exceptional care on panels which were made with great accuracy. Many people would like to know what was actually happening to those panels on a machine during flight, and he suggested that at the present stage it might be well to make some attempt to measure the strains during test flights. He felt that designers might be living in a fool's paradise if they framed rules hastily on the basis of experimental work without introducing some of the actual conditions which were likely to obtain during the various manœuvres it was possible to make during flight.

Mr. S. Lockwood Taylor (*Associate Fellow*): In dealing with overall instability, *i.e.*, failure by buckling involving stringers and frames, he put in a word for the orthotropic as against the grid theory. On the whole, he said, the results in Fig. 15 in the paper showed remarkably good agreement, except in the very extreme case of 100 per cent. of the inter-rib buckling load—which latter he did not consider to be a very practical case.

Discussing load diffusion, he said that the cases considered in the paper were all concerned with loads such as would be applied by the wings to the fuselage; but another case in which load diffusion occurred was where there was a system of self-balancing loads on a frame. Some years ago he had carried out theoretical work on the problem and had obtained some results showing that the effect of the adjacent frames was much greater than one would expect. Work of the same sort had been done abroad, and he suggested that Mr. Cox might care to add to his paper some references to that work.

Mr. F. Radcliffe (*Associate Fellow*): He said that whereas the paper had dealt with panels having stiffeners and ribs, which formed one extreme of the problem of thin metal construction, there was at the other extreme panels with fully corrugated stiffeners inside a smooth skin, which were often used for wings and fuselages. This type of panel was worthy of a little more attention, because many of the theories referred to in the paper could be examined at the other end of the scale by considering the fully corrugated sheet. He asked for the author's views on that problem, and whether he had confirmed any of his theories with that particular form of thin metal construction.

Mr. C. H. LEE (*Associate Fellow*): He asked for further information concerning the shear stress at which a panel would buckle, commented that the author had quoted one experimental result but had admitted that the experiment was not very representative of practice. It might be that the commencement of the inward pull on the bars bounding the panel did not coincide with the appearance of wrinkles in the sheet. The designer was interested to know the stress above which the plate behaved as a tension field panel. From experiments of which the speaker had personal knowledge it appeared as though the sheet was continuing to take the shear compression up to a stress considerably above that at which the buckles first became visible. However, these experiments had only just begun.

Mr. H. E. J. ROCHEFORT (*Associate Fellow*): He said that the problem which worried him most was that of distributing longitudinal concentrated loads into monocoque structures. Mr. Cox had published the results of his work on that problem in reference 70 and had there given three methods of distributing concentrated loads in a monocoque construction, stating that method A was the most finite and that method C, which was to distribute the concentrated load by shear across panels gave the heaviest construction of the three methods.

One can dismiss method B as a solution, as Mr. Cox himself stated (six months after the R. and M. was published) that it was fundamentally unsound. Method A was hardly practicable, so that method C alone remained. But Mr. Rochefort said he had had to dismiss Mr. Cox's method C because the transverse direct stresses had been neglected entirely, no mention having been made of them in the equations. Presumably, if Mr. Cox proceeded with that work and could set up the equations properly, they would have a solution.

For the same reason (neglect of transverse direct stresses) Mr. Rochefort had no confidence in the solutions of references 71, 72 and 73.

Turning to other sources of information, Mr. Rochefort's comment was that Wagner and Simon, Desch and Gropler and Ebner and Köller, reference 81, of Germany, had carried out a lot of work on the subject, Wagner having published results of his work as long ago as 1935; one would like to know whether the research people concerned at the National Physical Laboratory had studied those methods of solution, and if so, what were their comments.

He was interested particularly in a method used by Ebner and Köller, reference 81, in which they had treated the frames, the skin and the stringers as part of a " mechanism " for transmitting loads, obtaining a relation between the axial strain and the distortion, and a relation between that and the end load in the members. The American research people had also attempted to use that method, but had said that it was impracticable because one needed a machine for integrating; they had added that the best that could be done was by guesswork, reference 79. That did not help them much, however, and the only course at present practicable seemed to be to use Wagner and Simon's method.

A disconcerting feature was that this last method gave a shear flux at the point of application of the concentrated load, less than half as much as that obtained by Mr. Cox's method C.

Had he, Mr. Cox, studied the German reports, and was he in agreement with the methods at present in use? No doubt he had read the paper by Wagner and Simon, in which they had ignored the discontinuity in axial strains between the " integrating structure " and the monocoque. Was that error serious, and did it indicate that their (Wagner and Simon's) method was also fundamentally unsound?

Dr. A. G. PUGSLEY (*Associate Fellow*): He was particularly interested in Mr. Cox's tentative explanation of the premature failure of the curved panel. He wished that Professor Southwell, who was very interested in the problem, had been present to comment on Mr. Cox's work. The usual explanation was in terms of initial irregularity or eccentricity; that was the explanation so often used when one carried out tests and found the results differing from theory, that

he welcomed Mr. Cox's endeavour to supplement it by a little theory. One wondered whether Mr. Cox could include eccentricity in his strut calculations in order to ascertain how it affected his curves.

With regard to Mr. Cox's admittedly tentative suggestion that a stringer could not be stronger when connected to a sheet than when isolated, he said he gathered from the lecturer's own diagrams that the apparent stresses which the combination carried were sometimes rather higher than the stresses which the isolated stringer would carry. A possible explanation seemed to lie in the torsional stiffness of the stringer, for the sheet was often so attached to the stringer as to apply some constraint to any tendency for it to twist.

In regard to fuselages it was important to watch general collapse and general instability as distinct from local instability. The dimensions of the stringers and rings or formers commonly used did not increase in proportion to the increase in the diameter of the fuselage, but tended to remain fixed. In consequence, with large fuselages one was frequently rather impressed by the shallowness of the rings and stringers in comparison with the fuselage diameter; and as that situation developed it must seriously increase the likelihood of general instability. The testing of a large fuselage as a final check on its design tended to become more and more impracticable with increase of size, and consequently, he argued that, pending more accurate knowledge regarding general instability, one should aim at providing a fair margin of safety in this respect in large fuselages, particularly in those having negligible bulkhead or floor connections which might serve as stays, as in some large air liners.

Finally, he thanked Mr. Cox especially for the very excellent bibliography at the end of the paper.

Mr. W. Tye (*Associate Fellow*): In commenting on Mr. Cox's statement that the mean stress on a flat panel after buckling could be written very neatly in terms of f_b and n, he said that from Fig. 3 it was easy to appreciate that the stress-strain curve after buckling could be represented very easily by two straight lines. The question then arose as to whether that simple method would be equally applicable to a curved panel. The curved panel, the load deflection curve of which is illustrated in Fig. 4 had a curve with a high peak, the high peak being followed by a very deep trough. He believed the equations given in Part II (*c*) of the paper for the buckling stress and for the value of n referred both to flat sheets and to curved sheets; but the stress given for the curved sheet by those equations was, he believed, a stress at the top of the peak rather than at the bottom of the trough. He might be wrong in that belief; but if he were right, then it would clearly be impossible, using that stress for F_b, to represent the high peak and the low trough by a simple expression. It seemed possible, however, by assuming an artificially low value of f_b, to represent the curved sheets reasonably well by the f_b and n method, and he assumed that Mr. Cox had had to use some artificially low value of f_b in making his calculations on the cylinders. He asked if that were, in fact, the case.

Mr. D. R. Sherwin: He asked for information on the effect, on the collapsing load of a skin and stringer conbination, of using appreciably different grades of material for the skin; for example, the skin in one case might be of a sheet material having a proof stress of 24 tons/sq. in. and in the other 14 tons/sq. in. or lower. In the course of experience he had found that a skin and stringer combination having the lower grade skin often had as high or a higher collapsing load than the other, and he believed that this was due to the likelihood of a less regular surface in the higher grade sheet due to drilling and rivet sinking irregularities.

He asked the question because there had been considerable clamour from various aircraft firms for high grade sheet, and he failed to see how the manufacturer could be helped thereby when he could not work to a higher design stress. This was particularly bewildering when, by using a non-heat treatable

sheet having a low proof stress, the manufacturer could cut out two expensive heat treatments and simplify his forming operations.

The strength of the sheet and stringer combination must, in the end, be limited by the strength of its joints and he felt that a considerable amount of improvement in the strength of riveted and spot welded joints is necessary before the design stress of skin and stringer combinations can be greatly increased.

Mr. G. Beaumont (*Associate Fellow*) (*communicated*): Referring to Fig. 4 in the paper, it is shown that with an applied load of approximately $5\frac{1}{2}$ tons, the panel suddenly buckled and under the same strain, the load carrying capacity was suddenly reduced from $5\frac{1}{2}$ tons to 2.9 tons. In view of the fact that the panel in the buckled state was still capable of picking up additional load, it would be interesting to know if the final collapsing load would reach or exceed the load which was carried before buckling.

In the second and third tests, the resistance to buckling was very much reduced, but the characteristics after buckling remained the same as in the first test. This alarming reduction in stiffness suggests that some permanent strain was present in the panel, and although this feature does not appear to have been adversely affected by the second test, would it be fair to assume that further tests would have produced the same condition, or would the buckling have occurred at a still earlier stage? This is important from a design point of view, and suggests that a curved panel with a comparatively low R/t ratio should be designed so as not to buckle below the proof load condition. Presumably, there is some optimum value of R/t ratio at which the panel could be allowed to buckle below the proof load without damage to the material. Would it be possible to predict from the experimental work carried out, an approximate value of this R/t ratio?

Reply to the Discussion.

Replying to some of the questions raised in the discussion, he would deal first with the references made to the effective width method, in respect of which, he said, he had been misunderstood. He agreed with the Chairman and others that, provided the effective width were made to vary in the appropriate manner with the stress, that method and the f_b and n method were basically the same; the only reason for his preference for the latter method was that it avoided the necessity for solution by trial and error. His main objection to the effective width method was, however, that it was otherwise misleading; it was fundamentally unsound to regard a panel as being equivalent to a certain amount of sheet attached to the stringer, and to ignore the panel itself.

Dealing with Dr. Douglas's reference to the buckling of combinations of stringers and panels, he said the point was that nature never gave anything for nothing. If one put together a stringer and a panel which ordinarily would buckle into the same form—that was an assumption, of course—the combination would support merely the sum of the loads each part individually would have carried. Nevertheless, the two parts were now forced to buckle at the same stress, and that stress had to be intermediate between the stress at which the panel would buckle and the stress at which the stringer would buckle. The result was that the stringer avoided the necessity for carrying the whole load by transferring some of it to the panel; whilst on the other hand the centre of the panel, which ordinarily would be free from load, was now stressed because the panel was attached to the stringer.

With regard to curved panels, he said that Fig. 6—which was Fig. 4 with a dotted line added—was merely illustrative. He hoped to have time eventually to examine the behaviour of curved panels after buckling. He suggested that in that process the effect of initial deflection should be introduced at the beginning, so as to show how big an initial deflection was necessary to give the very considerable variations of buckling load experimentally recorded. If he could find

time he would examine the effect of initial irregularities in the behaviour of the supported strut.

Replying further to Dr. Douglas, he said the f_b and n method assumed that within the angle 2θ the proportion $(n-1)/n$ of the panel area carried the buckling stress, which was constant, and the rest of the sheet and the stringers carried the full stress, as before buckling.

The point made by Dr. Pugsley with regard to the prevention of torsional instability of the stringer by reason of its attachment to the sheet was a most important one, and he should have emphasised it in the paper. When a " top hat " section was riveted with the brim down on the sheet, its torsional rigidity was increased enormously, and failure by torsional instability might be entirely prevented. But when he had said that he did not expect the stringer attached to sheet to carry a higher stress than it would carry if it were tested alone he had intended to imply that the mode of failure should be the same in both tests. For open sections, the comparison might not be a practical one; but it was made for a special purpose to illustrate a theoretical argument. With regard to these comparisons between the stresses at which combinations of panels and stringers failed, he emphasised that " stress " had a definite meaning; the definition load/area was useless unless the load was uniformly distributed, and in all buckling problems it was preferable to define stress as strain × modulus.

Replying further to Dr. Pugsley, he suggested that general instability was not a danger to look forward to, but a desirable condition to be approached as closely as one dared. If the designer felt confident that there was no danger of general instability, he should also feel guilty of wasting material in the rings or frames. General instability was, however, the edge of a precipice, and with reference to a plea made by Dr. Taylor in defence of the orthotropic treatment, he pointed out that the grid method indicated that the edge of the precipice was a little nearer and, therefore, it was perhaps wiser to use this method than the established orthotropic method. He disagreed with Dr. Taylor's suggestion that 100 per cent. of inter-rib buckling was above the practical range. Dr. Pugsley's remarks showed that in practice the approach was actually from the other side; rings and frames had in the past been more than adequate to prevent all types of general instability, and the possibility of this type of failure was now becoming a practical issue.

He had not made reference in the paper to problems concerning rivets because he had felt that already he had taxed the hospitality of the Society's " Journal " far enough. A fair amount of work had been published on the strength of rivets, and probably the best way in which to deal with the matter would be to give the references. Undoubtedly, further work ought to be done; but the experimental technique necessary to discover exactly what was happening to a small unit such as a rivet was extraordinarily difficult. On the other hand, he agreed that the strength of rivets was an important matter.

The trouble with regard to diffusion of load by the shear type structure was that, owing to the lack of the exact solution and the virtual certainty that it would be practically useless if one had it, everyone was groping in the dark, with the result that, of course, all theoretical methods were open to objections. On the other hand, the analysis of the fan-type structure in his first paper was perfectly sound and correct, and he stood by it. The fan-type structure had been used, and he wished that more people would use it, because it was much easier to analyse. The practical objection to the fan-type structure lay in the detail of the end fixings of the fan ribs; in designing that detail it would probably be necessary to add a considerable amount of weight so that the inherent superiority of this type of structure might easily be lost. Moreover, the shear type necessitated less alteration to the other parts of the structure and was, therefore, preferable from that point of view.

He, personally, had thought that experimental results were in reasonable conformity with all the theoretical work, of which he had given a fairly complete

list of references, and he was surprised to hear Mr. Rochefort's suggestion that between two theoretical analyses there was a disparity as great as 2 to 1. However, he would look into the matter in order to see whether he could clear up this point. One question he had glossed over in connection with diffusion of load by shear was whether the sheet was in shear or in diagonal tension, and he thought it possible that the apparent discrepancy might be concerned with this alternative. He was afraid that in this matter of the manner in which the shear was carried, not only he himself but also the Americans and the Germans, tended to make the best of both worlds.

MR. H. L. COX ALSO WROTE IN REPLY:—

There are one or two points in the discussion on which he would like to make some further remarks. Dr. Pugsley and Mr. Russell referred to his suggestion that the buckling stress of the stringer attached to thin sheet would not be expected to exceed the buckling stress of the stringer alone. This suggestion was intended to apply only to a flat construction and he felt sure that the explanation of the greater value realised experimentally lies in the effect of lateral constraint due to curvature, which he attempted to illustrate by Fig. 12. This view is supported by the experimental observations to which Mr. Gerard referred, and he was indebted to him for adducing the valuable evidence afforded by the third cylinder tested at Bristol by the R.A.E., of which he had not the details. Mr. Sherwin asked whether a high value of 0.1 per cent. proof stress was important. In general, he would say that if failure occurs by instability the value of the proof stress is immaterial. Nevertheless, if the proof stress is very low, failure by direct crushing may supervene, and in any case a low value will cause collapse to ensue very soon after buckling. This effect may be important in cases such as that to which Mr. Gerard referred, in which marked bowing of the stringers was observed some time before collapse occurred.

With reference to Dr. Douglas's remarks with regard to the load deformation diagram for a curved panel shown in Figs. 4 and 6, it will be noticed that the upper part of the curve after buckling is slightly concave to the strain axis. This slight concavity is shown also in the theoretical curve for the supported strut, so that the similarity between the two curves is in this respect complete. He had more recently investigated the effect of initial curvature of the strut, and the results show just that rounding off of the cusp which would be expected. A very slight initial eccentricity causes the maximum load at buckling to be considerably reduced, so that experimental values of buckling load might be expected to vary between wide limits. An extension of this type of analysis to the actual case of a curved panel, both unstiffened and with stiffeners attached, is urgently required, and he felt sure the results would entirely account for the experimental behaviour of curved panels in a manner which would dispel Mr. Redshaw's doubts. At the same time this work would give valuable information as to the effect of slight damage to the structure, a problem to which Mr. Thurston and Mr. Beaumont referred, and as to the true buckling stress of a stringer when built into a curved sheet structure. With further reference to Mr. Beaumont's communication, in the case to which Figs. 4 and 6 refer, the load which caused buckling in the first test was never afterwards attained, although the appearance of the panel after unloading from the first buckle did not reveal any marked signs of permanent damage. Presumably, however, a permanent buckle of sufficient depth remained to cause the sharp cusp between the full and dotted lines in Fig. 6 to be rounded off giving the much lower peak between these two lines obtained in the second and third loadings. This reduction of buckling load may appear excessive, but reductions of comparable order are indicated theoretically for the supported strut due to initial eccentricity sufficiently slight to be almost unobservable. Reductions of this order are, however, confined to cases in which the R/t ratio is relatively small. He certainly agreed with Mr. Beaumont that such panels should be designed so that buckling should

never occur, and the panel should be scrapped if ever it were inadvertently buckled. The high values of R/t ($>$ 1,000 say) curved panels behave very similarly to flat panels; but he was afraid that little really valuable information could be given relating to intermediate values of R/t until the theoretical analysis of the curved panel should have been more fully developed. The empirical values of f_b and n quoted in the paper are based on about fifty experimental results, due consideration being paid to the theoretical values of buckling load. With reference to Mr. Tye's question, for values of R/t greater than about 500 the empirical f_b and n lines correspond reasonably closely to the troughs of the experimental diagrams; but for lower values of R/t the empirical line lies well above the trough, although it is still well below the primary buckling load. As a general recommendation, he would suggest that the empirical values of f_b and n can be used with fair confidence for values of $R/t > 500$; that, for values of $R/t < 300$, the panel should be designed to work entirely unbuckled; and that intermediate values of R/t should be avoided. He was in entire agreement with Dr. Douglas and Mr. Francis that a number of analyses of practical structures by all available methods should be worked out in detail and compared with experimental results, and he would support Mr. Radcliffe's suggestion that the case of a corrugated sheet should be included as the limiting case of a stiffened skin. Unfortunately, in present circumstances there appears to be little prospect of this work being done.

The question of the " partial tension diagonal field " to which Mr. Lee referred is a very perplexing problem. The experiments, the results of which are shown in Figs. 17 and 18, were of course only preliminary; the problem is treated in much more detail in reference 27, and it is hoped that the photo-elastic measurements now being carried out under the supervision of Professor Hill will provide much more detailed information. He did not think there can be any doubt that the exact balance between the diagonal tensile and compressive principal stresses into which pure shear can be resolved must be upset the moment the sheet starts to buckle; but the difference between these stresses, which is, of course, a measure of the side thrust on the edge bars, appears to increase only slowly as the buckled form develops. In the case of the thicker panel tested at the N.P.L., even when the wave depth was of the order of $\frac{1}{2}$ inch and quite permanent, the sheet could still transmit compression, although of course the compressive stress was small. Theoretically, the state of pure tension diagonal field can never be set up in any sheet of finite thickness by any finite shear; but in practice with thin sheet this condition may be very closely approached.

With regard to the question of rivets, in which Dr. Douglas and Messrs. Francis, Gerard and Sherwin expressed interest, he appended to this reply three references which may be useful. It is apparent from Figs. 8 and 11 that the reduction of strength due to too wide a rivet spacing, leading to buckling of the sheet between rivets before the stringers themselves buckle, may be quite considerable; but as Mr. Gerard pointed out the effect of this local buckling in causing premature failure of the stringer may be even more important. In this connection reference 84 is particularly interesting. The fixity coefficient of 1.7 used in the analysis of Figs. 8 and 11 was determined entirely empirically, but the value seems reasonable in relation to the practical conditions. The question of the actual strength of the rivets, which was raised by Mr. Francis, has received very little attention. Certainly, if the rivets were omitted the sheet would buckle independently of the stringer so that the rivets must transmit normal loads from stringer to sheet. So far as he knew the magnitude of these loads has never been investigated, although theoretically the problem presents no special difficulty. The rivet problem arises also in the transmission of concentrated load to monocoque structures, but in this case it is the shear strength and rigidity of the rivets which is important.

With regard to the diffusion of concentrated loads, he would not add very much to the verbal reply he made on May 4th. Wagner and Simon's paper,

like many other German references, deals only with structures invariant in section along their lengths. It seems to him that structures of this type can have only a very limited range of application in practice (refs. 72 and 73), so that he had not given this work a great deal of attention. The fact that in Wagner and Simon's paper all the stringers are of constant section renders comparison with references 70, 72 and 73 impossible, because in all this latter work some or all of the stringers are tapered. It is not surprising that the shear stress found by Wagner and Simon is less than half that indicated in reference 70, because in the latter case these stringers were tapered with the special object of increasing the rate of transfer load, which implies an increase in the shear stress. He, like the Americans, had found Ebner and Köller's analysis (reference 81) extraordinarily difficult to follow, and he was not convinced that the assumptions on which it is based were valid. The neglect of the discontinuity in axial strains at the joint between the diffusing structure and the monocoque is associated with the conception of " 95 per cent. equalisation length " adopted in references 71 to 73. Certainly, these assumptions must introduce error, the magnitude of which will be determined entirely by the degree of equalisation obtained. The assumption is not strictly essential to the method of reference 71, and an example of the use of the method without recourse to this assumption is at present being worked out.

References 77 and 79 show that the Americans have adopted exactly the same method of analysis as that developed independently in this country, and the experimental results obtained in America tend to confirm the results of this theory. Certainly he agreed with Mr. Francis that much more experimental work is required, but the experimental technique required is very complicated. The limitations of the present theory are discussed in some detail in reference 73, and the need for further analysis, taking into account the effect of cross tensions, is there made obvious; at the same time this discussion suggests that the error introduced by the neglect of the cross tensile stresses is seldom likely to be serious.

In conclusion, he would like to express his thanks to all those gentlemen who have made such interesting contributions to the discussion and to apologise for the great length of the reply. He felt with the Chairman the urgent need of some service which will close the gap between the design office and research laboratory more effectively. The Society does a great deal to this end; but in present circumstances contact between research and design should be on a day-to-day rather than a month-by-month basis.

On the motion of the Chairman, a hearty vote of thanks was accorded Mr. Cox for his paper.

TESTS OF A GUST-ALLEVIATING FLAP IN THE GUST TUNNEL.*

By PHILIP DONELY and C. C. SHUFFLEBARGER.

SUMMARY.

Tests were made in the N.A.C.A. gust tunnel to determine the effectiveness of a long-period dynamically overbalanced flap in reducing aeroplane accelerations due to atmospheric gusts. For two gust shapes, one gust velocity, one forward velocity, and one wing loading, a series of flights was made with the flap locked and was then repeated with the flap free to operate. The records obtained were evaluated by routine methods.

The results indicate that the flap reduced the maximum acceleration increment 39 per cent. for a severe gust with a representative gust gradient distance of 8 chord lengths and that, for an extreme gust shape (a sharp-edge gust), the reduction was only 3 per cent. The results also indicate that the flap tended to reduce the longitudinal stability of the aeroplane. Computations made of the effectiveness and the action of the flap were in good agreement with the experimental results.

INTRODUCTION.

From time to time, various methods of reducing the acceleration due to gusts encountered by an aeroplane in flight have been suggested. Among these methods

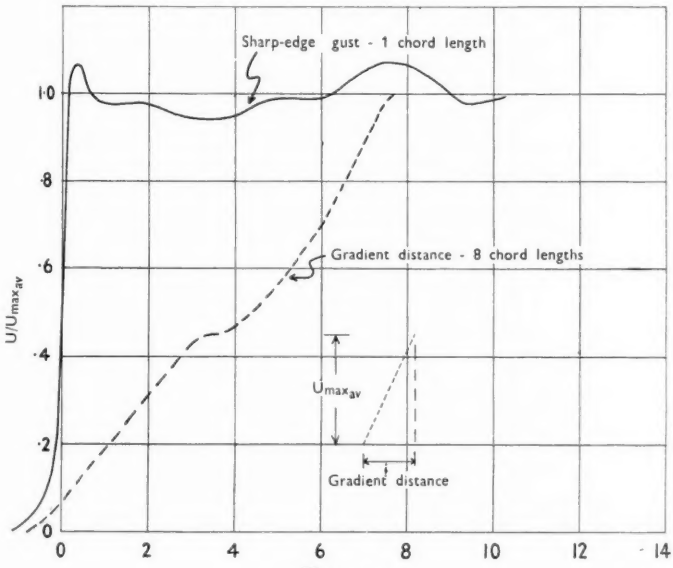

FIG. 1.

Horizontal distance from leading edge of gust tunnel, chord lengths. Velocity distribution through jet.

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are spring-mounting the fuselage to the wings and the use of automatic flaps controlled by the motion of the air or the aeroplane. Although interest has been shown in these suggestions for improving the riding comfort of aeroplanes, the effectiveness of such devices is difficult to compute and to investigate experimentally.

The N.A.C.A. gust tunnel now offers a convenient means of investigating gust-alleviating devices under known conditions. The present investigation was undertaken to determine the effectiveness of a long-period dynamically overbalanced flap in reducing the normal accelerations due to known gusts.

Tests were made in the N.A.C.A. gust tunnel during the spring of 1938 on an arbitrary aeroplane model for two gust shapes.

Apparatus.

The gust tunnel and the auxiliary equipment have been described in reference 1. The gust shapes used during the investigation are shown in Fig. 1.

Fig. 2.

Aeroplane model.

The aeroplane model (Fig. 2) was equipped with a rectangular wing. The general dimensions and characteristics of the model are given in Table I. The characteristics of an aeroplane 13.4 times as large have been included in Table I for purposes of comparison.

Table I.

Characteristics of Aeroplane Model.

	Model.	Hypothetical Aeroplane.
Weight, lb.	1.62	3910
Wing area, sq. ft.	1.65	297
Wing loading, lb. per sq. ft.	0.98	13.2
Span, ft.	3.09	41.4
Mean geometric chord, ft.	0.535	7.2
Centre of gravity, per cent. M.A.C.	25	25
Fundamental wing period, sec.	0.0294	0.1076
Moment of inertia, mk_Y^2, slug ft.^{2}	0.00786	3420
Gust velocity, f.p.s.	16.9	25.2
Forward velocity, f.p.s.	63.5	232
Span of flap, per cent. wing span	100	100
Chord of flap, per cent. wing chord	10	10

The aeroplane model was conventional in all respects except that it was equipped with a dynamically overbalanced flap. Fig. 3 shows the details of the flap mechanism. The flap was attached to the wing by means of 12 pivot and socket bearings to keep the friction a minimum. At each hinge (Fig. 3), an arm 1.2 inches long, which supported a 0.27 ounce weight at its extremity, was attached

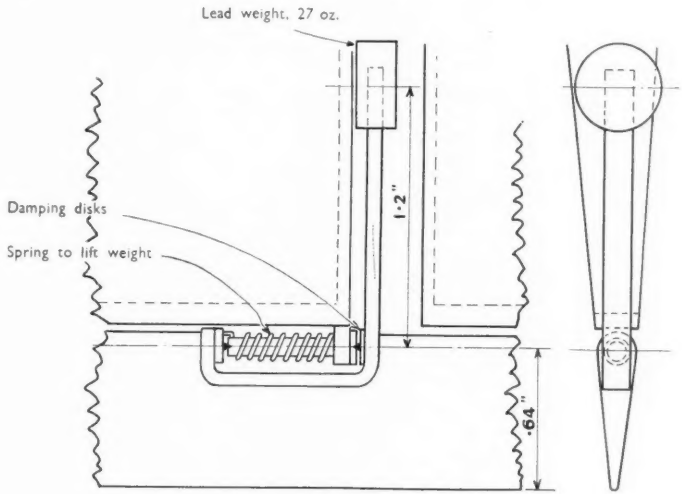


FIG. 3.

Detail of flap hinges. Six hinges spaced six inches along span.

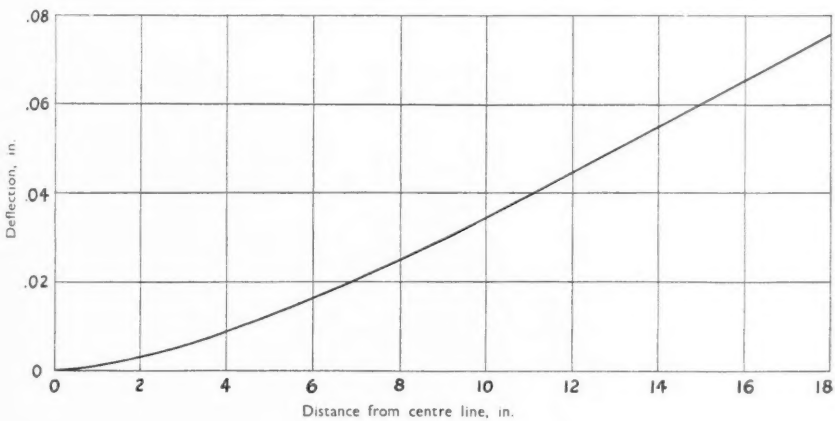
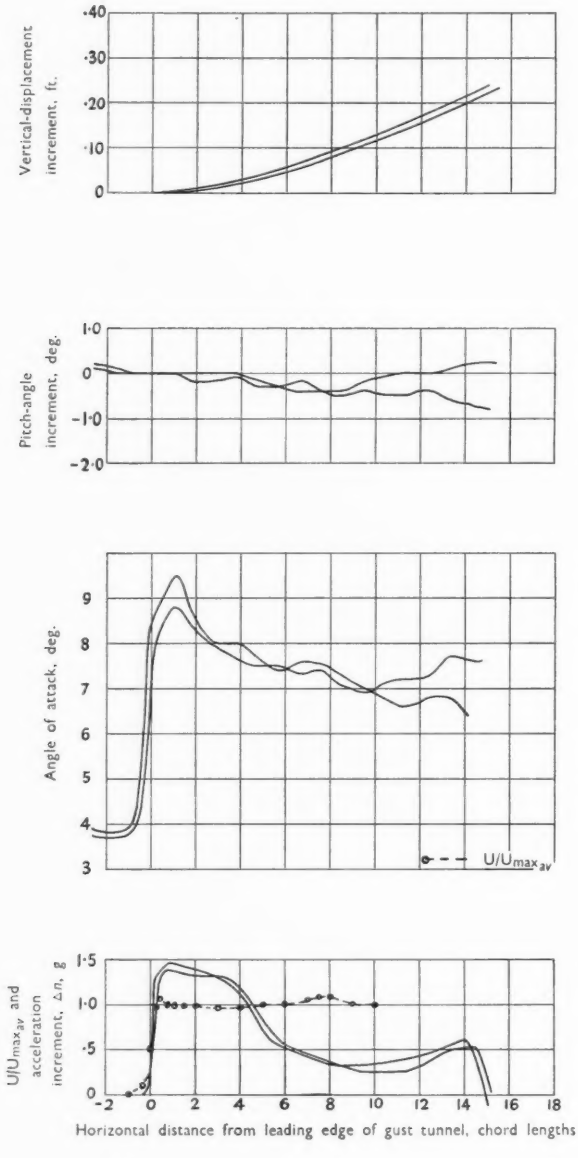


FIG. 4.

Wing deflection curve, load factor 1.16.

to the flap. The overbalance caused in this manner was counteracted by a coiled spring at each hinge. Small discs (Fig. 3) were used to provide damping, which could be varied by inserting oil of suitable viscosity between the discs.

The effective period of the flap could not be experimentally determined owing to the nature of the mechanism. An approximate calculation, however, indicated



(*b*) Flap free

FIG. 5.

Continued histories of events.

an effective period of 1.25 seconds, which is quite large when compared with the normal value for the time from zero to maximum acceleration increment (0.03 to 0.14 second). The relative lengths of the times indicate that the mass attached to the 1.2 inch arm would tend to maintain a fixed path in space when the model was vertically displaced. The flap displacement would therefore be a direct function of the vertical displacement increment of the aeroplane model for moderate flap displacements and for the periods of time considered here.

As all computations were based on a rigid wing, the wing was made as rigid as possible. In order to obtain a measure of the wing rigidity, the static wing deflection curve and the natural period were experimentally determined. The wing deflection curve for a load factor of 1.16 (Fig. 4) was obtained for a uniform span loading. The natural wing period, determined with the model elastically supported, is included in Table I.

In addition to the regular apparatus and instruments used in all tests at the gust tunnel (reference 1), a high speed motion picture camera was used to record the flap motion during part of two flights. The pictures were taken at about 2,000 frames per second and covered about 2 to 3 feet of the traverse of the gust tunnel by the model.

Tests.

The test procedure consisted in flying the model over the gust tunnel under identical conditions except for the flap, which was either locked or free. The tests were made for two gust gradient distances of one and eight chord lengths, one forward velocity, one gust velocity, and one value of wing loading. The velocities and the wing loading are included in Table I; the gust shapes are shown in Fig. 1. Five flights were made for each condition to obtain mean values of the acceleration increment.

In addition to the main series of tests, a few flights were made to obtain high speed motion pictures of the flap motion during part of the traverse of a gust with a gradient distance of eight chord lengths.

Results.

The records obtained during the tests were evaluated to give histories of events during entry into and traverse of the gust. Sample histories of uncorrected results for repeat flights for each test condition are shown in Figs. 5 and 6.

The maximum acceleration increments for all runs were corrected to the nominal values of forward velocity and gust velocity given in Table I. The resulting values are shown in Fig. 7 for the flap-locked and the flap-free conditions as a function of the gust gradient distance.

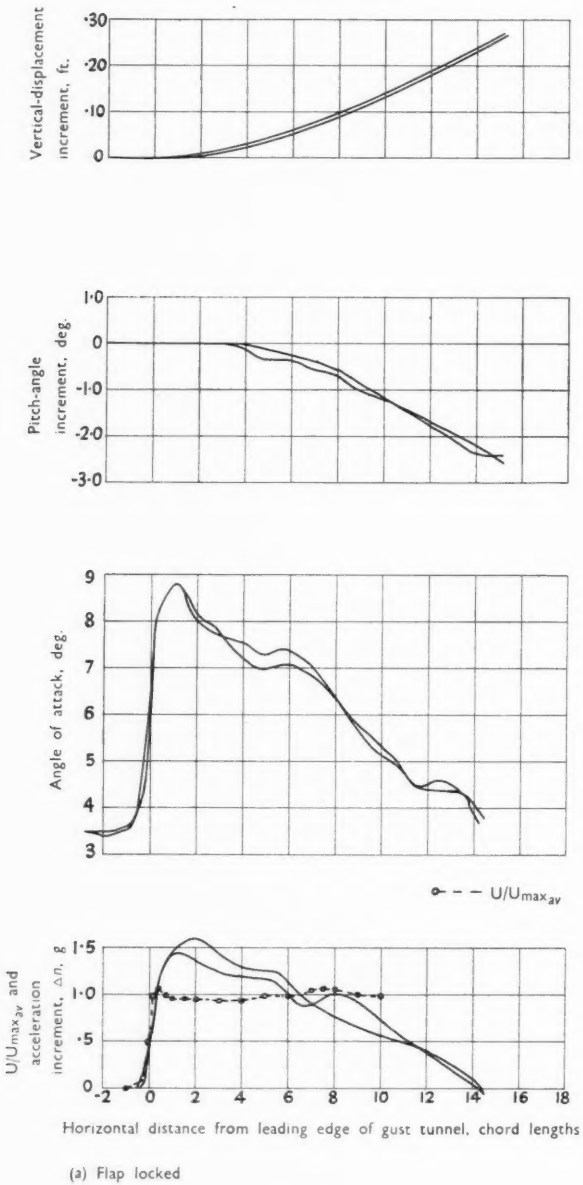
The flap effectiveness, defined as the percentage reduction in maximum acceleration increment due to the flap, was computed for each gradient distance from the data of Figs. 7 (*a*) and 7 (*b*) and is shown in Fig. 8.

The high speed motion pictures of the flap motion were evaluated to obtain the flap displacement as a function of the distance penetrated into the gust. The results are given in Fig. 9.

Precision.

The measured quantities are estimated to be accurate within the following limits for any run:—

Acceleration increment	±0.1 g.
Forward velocity	±1.0 foot per second.
Gust velocity	±0.1 foot per second.
Pitch displacement increment ...	±0.2°.
Vertical displacement increment ...	±0.01 foot.
Flap displacement	±2°.



(a) Flap locked

FIG. 6.

Histories of events in a sharp-edge gust.

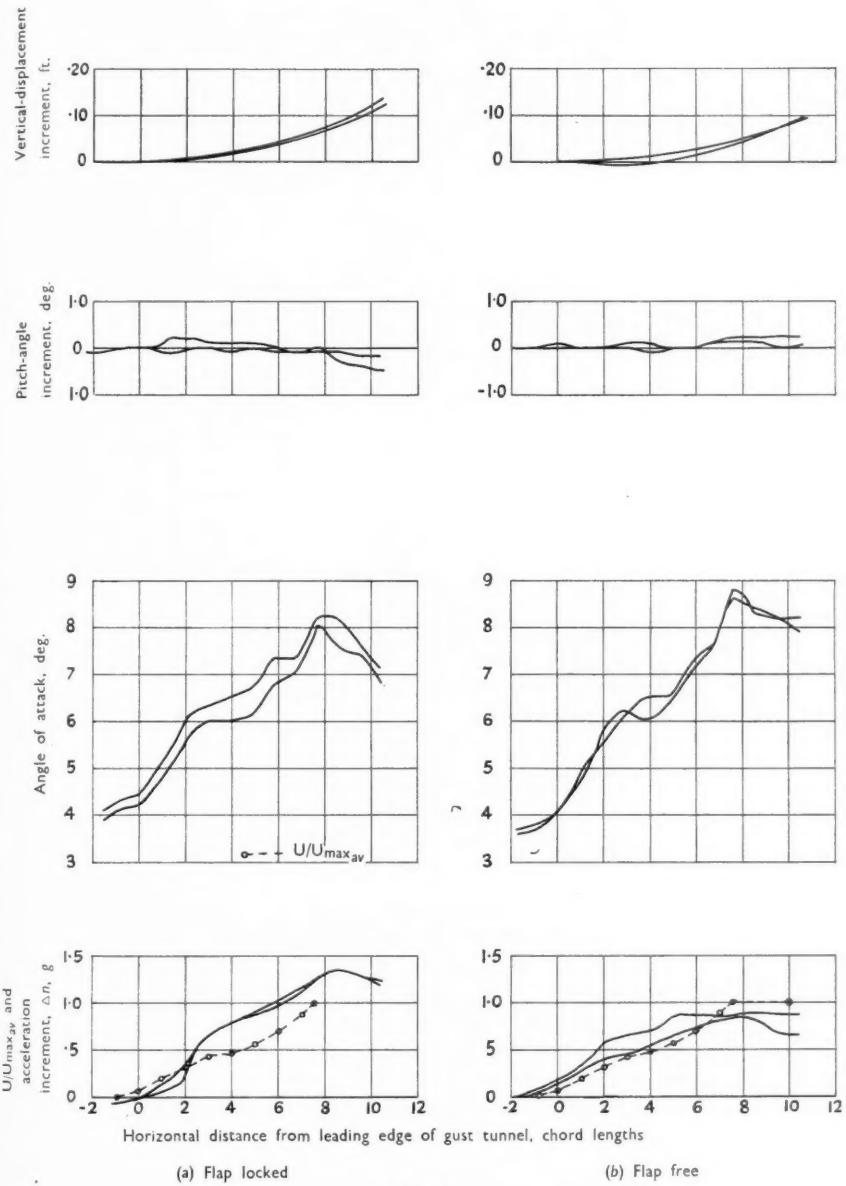


FIG. 6.

Histories of events in an eight-chord length gust.

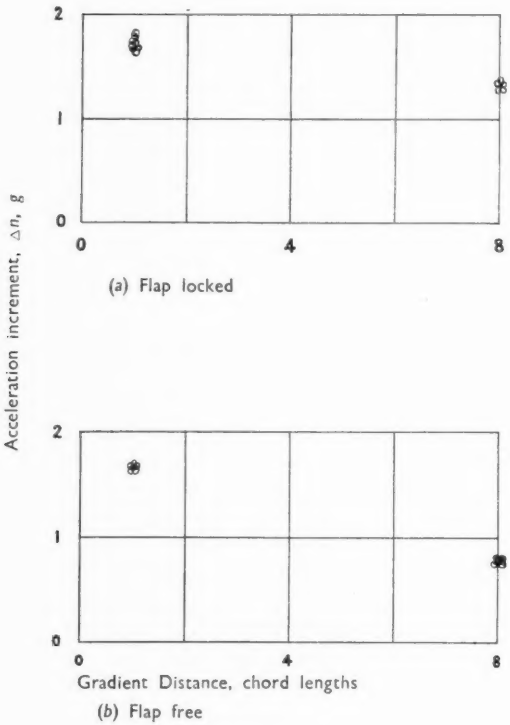


FIG. 7.

Variation of acceleration increment with gradient distance.

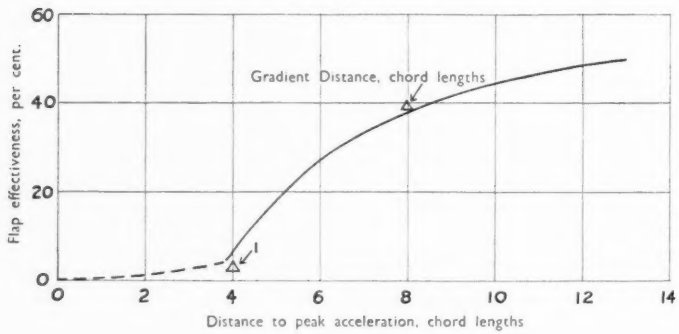


FIG. 8.

Variation of flap effectiveness with distance to peak acceleration.

An approximate calculation based on the natural period (Table I) and the wing deflection curve of Fig. 4 indicates an error in acceleration increment due to wing flexibility of not more than 2.5 per cent. This error is felt to be well within the accuracy of the other measurements and will therefore be neglected.

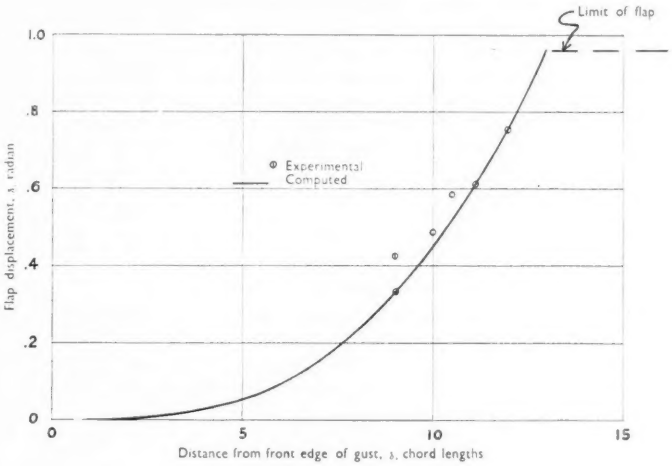


FIG. 9.

Variation of flap displacement with distance penetrated into eight-chord length gust.

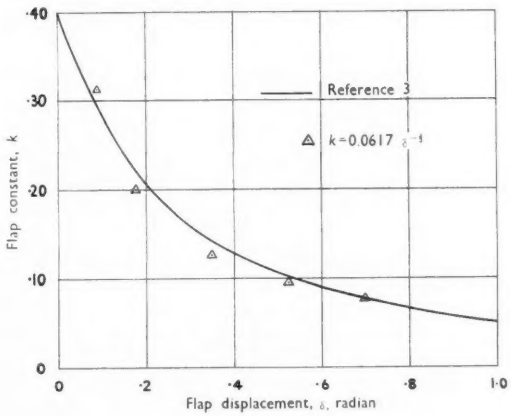


FIG. 10.

Variation of flap constant with flap displacement.

DISCUSSION.

As previously mentioned, the flap mechanism was so designed that the flap displacement, δ, was a direct function of the vertical displacement increment of the model for moderate flap displacements. As a result of this method of operation, the flap should be relatively ineffective for sharp gusts, but its effectiveness

should tend to increase as the gradient distance increases. Inspection of Fig. 8 substantiates this reasoning, the results indicating a flap effectiveness of only 3 per cent. for a sharp edge gust as compared with about 38 to 40 per cent. for a gust with a gradient distance of eight chord lengths. In the practical application of this mechanism, the small reduction in acceleration in a sharp edge gust can be ignored because the sharp edge gust represents an extreme gust shape that is indicated by unpublished data to be seldom encountered in flight.

Attempts to calculate the effectiveness of the flap mechanism by use of the unsteady lift functions given in reference 2 for a flapped wing indicated that the theoretical flap constant (rate of change of effective angle of attack with flap displacement), developed for a sealed flap, would give unsatisfactory results. The flap used in this investigation was unsealed, and the data on flapped wings given in reference 3 indicate that the flap constant is a function of the flap displacement. Fig. 10 gives the variation of the flap constant k with flap displacement for a 10 per cent. chord flap such as used on the present model. In view of this result, the computations were repeated with the varying flap constant of Fig. 10.

The analysis was made with the following assumptions:—

1. The acceleration increment is a linear function of the distance penetrated into a linear gradient gust.
2. The flap displacement varies directly with the vertical displacement increment of the model; that is, the mass attached to the flap maintains a fixed path in space when the model is displaced.
3. The pitch of the aeroplane model is negligible to peak acceleration.
4. Whether the flap is free or locked, the maximum acceleration increment will occur at the same distance from the start of the gust (equations (3) and (4) of reference 4).

The equation for Δn, the maximum acceleration increment, is:—

$$\Delta n = (dC_L/d\alpha)\,(Sq/W)\,(1/V)\int_0^{s_1} C_{L_g}\,(s_1 - s)\,(dU/ds)\,ds$$

$$-(dC_L/d\alpha)\,(Sq/W)\,(K_1/V)\int_0^{s_1} C_{L_\alpha}\,(s_1 - s)\,\Delta n\,(s)\,ds$$

$$-(dC_L/d\alpha)\,(Sq/W)\,K_2\int_0^{s_1} C_{L_\alpha}\,(s_1 - s)\,\{\,d\,(k\delta)/ds\,\}\,ds \quad . \quad . \quad (1)$$

where

Δn is acceleration increment at point of maximum gust velocity for a linear gradient gust.
$dC_L/d\alpha$, slope of wing lift curve per radian.
S, wing area.
q, dynamic pressure.
W, aeroplane weight.
V, forward velocity (assumed constant).
U, gust velocity at any point.
s, distance aeroplane has penetrated into gust, chord lengths.
s_1, gradient distance, chord lengths.
C_{L_g}, unsteady lift function for an aerofoil penetrating a sharp edge gust.
C_{L_α}, unsteady lift function for a sudden change of angle of attack, $C_{L_\alpha} = 1 - 2/(4 + 2\,s)$ (derived from equation (1a), reference 5).
δ, flap displacement.
k, flap constant (Fig. 10). For the purpose of this analysis, $k = 0.0617\,\delta^{-2/3}$.
K_1, K_2, $K_3 \ldots K_n$, constants.

Inspection of equation (1) discloses that the acceleration increment is made up of three components: that due to the action of the gust, that due to the vertical velocity of the aeroplane, and that due to the motion of the flap. The first term can be written as $(dC_L/d\alpha)(SqU_1/WV)(A/s_1)$ for the gradient gust or as $(dC_L/d\alpha)(SqU_1/WV)(\eta_0)$ for a sharp edge gust, where U_1 is the gust velocity at s_1 and where A and η_0 are the functions of s_1 given in reference 4. This term represents the acceleration of the aeroplane when the lag in lift is taken into account but the vertical motion of the aeroplane is neglected. For convenience, it will be designated Δn_0. The last two terms depend on the final value of the acceleration and are not so easily obtained.

Since the acceleration increment is assumed to be a linear function of time or of s, the second term of equation (1) can be reduced to

$$(dC_L/d\alpha)(Sqc/WV^2)(\Delta n/s_1)\int_0^{s_1}[1-2/\{4+2(s_1-s)\}](sds)$$

$$=(dC_L/d\alpha)(Sqc/WV^2)(\Delta n/s_1)[s_1^2/2+(s_1+\{(4+2s_1)/2\}\log_e\{4/(4+2s_1)\})]$$
$$=K_3(\Delta n) \text{ for a particular value of } s_1.$$

This equation indicates that the component due to the vertical motion of the aeroplane is a function of the impressed acceleration and the gradient distance s_1.

The third term of equation (1) contains no direct expression for Δn but is dependent on Δn, since δ is a function of the double integral of the acceleration increment. When δ is computed from the vertical displacement of the model, it is found that

$$\delta=K_4(\Delta n/s_1)s^3$$

so that

$$k\delta=K_5(\Delta n/s_1)^{1/3}s$$

and

$$d(k\delta)/ds=K_5(\Delta n/s_1)^{1/3}$$

When $K_5(\Delta n/s_1)^{1/3}$ is substituted for $d(k\delta)/ds$ in the third term of equation (1), the following expression is obtained:—

$$(dC_L/d\alpha)(Sq/W)K_6(\Delta n/s_1)^{1/3}\int_0^{s_1}[1-2/\{4+2(s_1-s)\}]ds$$

$$=(dC_L/d\alpha)(Sq/W)K_6(\Delta n/s_1)^{1/3}(s_1+\log_e\{4/(4+2s_1)\})$$

or the third component is $K_7(\Delta n)$ for a particular value of s_1.

When the expressions obtained for the three terms of equation (1) are introduced into the original equation, the solution for a particular value of s_1 is obtained by a process of iteration, as:—

$$\Delta n_1=\Delta n_0-K_3(\Delta n_0)-K_7(\Delta n_0)^{1/3}$$
$$\Delta n_n=\Delta n_0-K_3[\Delta n_{(n-1)}]-K_7[\Delta n_{(n-1)}]^{1/3}$$

The iteration process converges quite rapidly and is easy to carry out if the last two terms are plotted as functions of Δn for different values of s_1.

In the present case, the computation was made for several values of the gust gradient distance and for several gust velocities. The resulting curves, given in Figs. 8 and 11, indicate that the flap effectiveness increases as the gradient distance increases and as the gust velocity decreases. The experimental values from the gust tunnel tests, shown in Fig. 8, indicate excellent agreement between calculation and experiment. It appears, therefore, that the flap would be more effective in smoothing out the small bumps than the large ones. The computed flap displacements have been included in Fig. 9. The results indicate excellent agreement with the experimental data in spite of the assumption that the sine of the angle was equal to the angle. The excellent agreement, however, may be due to compensating errors in the assumptions used in the development of the equations.

The effect of the flap on the longitudinal stability of the aeroplane is adverse, as would be expected, in that it reduces the pitch of the aeroplane in the gust. This reduction is shown by the pitch increment curves of Figs. 5 and 6. A comparison of the curves for the free flap and the locked flap shows a marked decrease in the negative pitch. This decrease is particularly noticeable when Figs. 5 (*a*) and 5 (*b*) are compared.

It might be well to point out that a device which tends to maintain the wing lift at a constant value will also tend to reduce the manœuvrability of the aeroplane. Any acceleration imposed on the aeroplane to change its flight path will be modified by the influence of the flap unless provision is made for the pilot to override the flap action when using the controls.

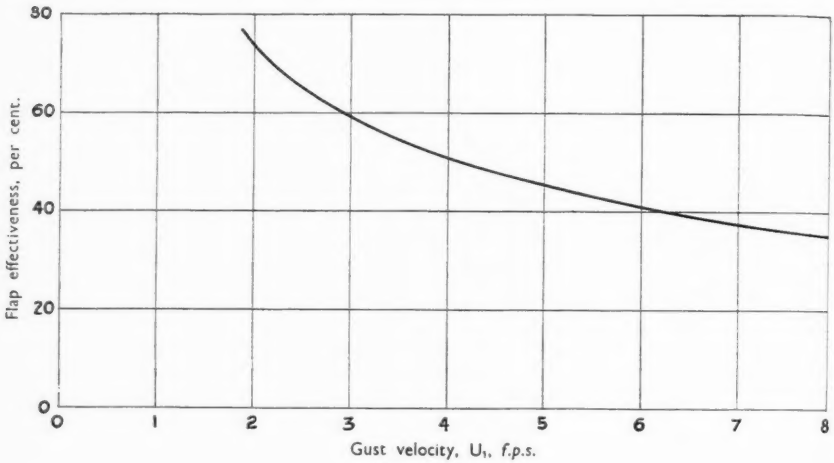


FIG. 11.

Variation of flap effectiveness with gust velocity for an eight-chord length gust.

CONCLUSIONS.

For the aeroplane model tested, the results indicate that the flap reduced the maximum acceleration increment 39 per cent. for a severe gust with a representative gust gradient distance of eight chord lengths and, for an extreme gust shape (a sharp edge gust), the reduction was only 3 per cent. The results also indicated that the flap tended to reduce the longitudinal stability of the aeroplane. Computations made of the effectiveness and the action of the flap were in good agreement with the experimental results.

Langley Memorial Aeronautical Laboratory,
N.A.C.A.,

December 8, 1939.

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ABSTRACTS FROM THE SCIENTIFIC AND TECHNICAL PRESS.

Issued by the
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(Prepared by R.T.P.)

No. 75. FEBRUARY, 1940.

Co-operation Between the Army and the Air Force. (O. Teplinski, Luftwehr, Vol. 6, No. 3, March, 1939, pp. 92-95. From the Russian, Wjestnik Wosduschnovo Flota, August, 1938.) (75/1 U.S.S.R.)

During the fighting in Spain and China the utilisation of aircraft against ground troops on the actual field of battle has played such an important *rôle* that some critics have looked upon this method of co-operation as the chief *rôle* of an air force. It must however not be forgotten that the number of aircraft participating in these campaigns was relatively small and that, especially in Spain, the armies lacked the equipment in artillery considered normal in a major war. Under these conditions participation of the aircraft in ground fighting may play a decisive part in the issue of a battle, especially if the moral effect of this new weapon is effective. The purpose of war is, however, not to win a battle but to win the campaign, and this can only be done if full use of the air arm is made by means of attacks far into the interior of the enemy territory. A large scale offensive by an army or fleet requires a preliminary extensive air reconnaissance. When the attack is launched, the air force will be called upon again to prevent the enemy bringing up reinforcements and supplies. The air force may indeed take part on the actual battle field, but such action will be limited (protection of mechanised units, bombing of machine gun nests, etc.). In no case should such co-operation be regarded as a major *rôle* of the air force. Only by making full use of its destructive capacity " in depth " will the air force come into its own. Moreover, these long distance attacks must be exactly co-ordinated with the exigencies of the situation as a whole. This is true " army co-operation " and requires a high degree of skill for its proper employment.

American Estimate of Relative Rates of Production of Military Aircraft by the Belligerents and the U.S.A. (Inter. Avia., No. 691, 4/1/40, pp. 1-2.) (75/2 U.S.A.)

According to H. W. Baldwin, military correspondent of the " New York Times," the German aircraft production was of the order of 1,600 machines per month in December, 1939. For the same period the rates of production of Great Britain, France and the U.S.A. are given as 1,000, 400 and 350 respectively. The American production should be more than doubled by the spring of 1940; only a proportion of these machines will, however, be available for export. The German December production must not be regarded as a limit, and ultimate production rates as high as 5,000 a month have been mentioned. These are regarded as unduly optimistic. It seems to be established, however, that Germany

should be capable of maintaining her present numerical superiority in aircraft right up to the early summer of 1940, and that the Allies, taking into account American purchases, cannot be expected to take the lead before the autumn of 1940 or the spring of 1941.

Characteristics of the Projectiles for the 20 *mm. Madsen Gun.* (Rev. de l'Arm. de l'Air, No. 119, Nov.-Dec., 1939, p. 660.) (75/3 Denmark.)

The following types are available:—

1. Explosive.	Shell.
2. Explosive with special fuse.	Shell.
3. Explosive tracer.	Shell.
4. Incendiary.	Shell.
5. Practice.	Shell.
6. Tracer.	Bullet.
7. Armour piercing tracer.	Bullet.
8. Practice tracer.	Bullet.
9. Explosive armour piercing.	Bullet.
10. Practice.	Bullet.

The characteristics of these shells and bullets are given in the following table:—

Type.	1	2	3	4	5	6	7	8	9	10
Weight of bullet (gm.) ...	113	113	126	113	113	126	146	146	136	136
Weight of driving charge (gm.)	42	42	38	42	42	38	41	41	41	41
Weight of explosive charge (gm.)	9.5	9.5	6.5	—	—	—	—	—	3.5	—
Range (m.)	4700	4700	2100	—	4700	—	5500	—	5000	5000
Min. time of burning of tracer (seconds)	—	—	6	—	—	9	7	7	—	—
Corresponding vertical range (m.)	—	—	1900	—	—	2400	—	—	—	—
Max. vertical range (m.) ...	2950	2950	1900	—	—	—	—	—	—	—
Distance at which 30 m/m. armour (450 Brinell) is pierced (m.)	—	—	1900	—	—	—	500 to 600	—	400 to 500	—

The propellant is nitrocellulose and the explosive tetryl (except in the case of No. 9 charged with black powder and No. 4 charged with tetryl plus incendiary matter). The maximum pressure is of the order of 2,700 kg./cm.^{2}. Radius of curvature of head of shell 2.6 calibre. No. 2 and 3 are fitted with instantaneous fuses together with a safety device ensuring automatic destruction at the end of 13 and 6 seconds respectively.

Characteristic of the Oerlikon 20 *mm. Cannon.* (Rev. de l'Arm. de l'Air, No. 119, Nov.-Dec., 1939, p. 661.) (75/4 Switzerland.)

The 20 mm. Oerlikon cannons are of two types. Type A is intended for turret use and is operated by hand. The breech is relatively heavy, and the recoil spring weak, and the rate of fire low. The magazine holds 15 to 30 rounds. Type F has a high rate of fire and is mounted in the wing, the magazine holding either 45, 60, 75 or 100 rounds.

In each type the addition of the letter F, L or S denotes that the muzzle velocity is 600, 750 or 900 m./sec. respectively.

Type	AF	AL	AS	FF	FFL	FFS
Calibre	20	20	20	20	20	20
Length (in calibres)	38	60	70	38	60	20
Muzzle velocity (m./sec.) ...	600	750	900	600	750	900
Rate of fire (rounds/min.) ...	450	370	300	520	450	400
Total length (mm.)	1331	1823	2066	1331	1823	2066
Weight (kg.)	25	92	42	23	30	39
Weight of cartridge (gm.) ...	192	211	240	192	211	240

For the 37 mm. cannon of the American Armament Corporation the following particulars apply :—

Muzzle velocity, 823 m./sec.
Rate of fire, 90 per minute.
Weight of shell, 780 gm.
Force of recoil, 771 kg.
Weight (without mounting), 200 kg.

Effect of Aircraft Bombs. (Rev. de l'Arm. de l'Air, No. 119, Nov.-Dec., 1939, p. 662-665.) (75/5 France.)

The following table gives the probable bombing errors, E_p (range) and E_d (direction) for horizontal launching at various altitudes and speeds, utilising the S.T.Ac. bombsight :—

Speed at release	Height of Release (m) 500		1,000		2,000		3,000		4,000		5,000		6,000	
	E_p	E_d	E_p	E_d	E_p	E_d	E_p	E_d	E_p	E_d	E_p	E_d	E_p	E_d
150 km./hr. ...	20	25	30	40	60	65	90	90	120	115	150	135	185	160
200 km./hr. ...	30	35	45	55	80	90	120	120	155	150	200	180	240	210
250 km./hr. ...	35	55	55	75	100	115	145	150	195	185	245	225	300	260
300 km./hr. ...	40	70	65	95	115	140	170	185	230	230	285	275	345	320

In a further table, the author gives a list of objectives together with suitable bombs for their attack. A 50 kg. bomb dropped on a rail track from an altitude of 1,000 m. produces a funnel-shaped hole, 2 m. deep and 6 m. diameter. The track is displaced over a distance of 40 to 50 m. When dropped on a road surface, the hole is slightly smaller. In order to destroy landing surfaces, a minimum of one bomb for each 50 m. square is required.

The Rôle of the Fighter in Modern Aerial Warfare. (C. Jeromez, Flugwehr und Technik, Vol. 1, No. 11-12, Nov.-Dec., 1939, pp. 272-274.) (75/7 France.)

In the 1914 war, more than 90 per cent. of all the aircraft were brought down by surprise attacks carried out at very short range. The enemy was " assassinated " from behind, from a distance of less than 20 m. The author is of the opinion that similar tactics will still apply under present conditions. Firing from a distance rendered possible by the increased calibre of the weapons employed is very uncertain and has the great disadvantage of warning the enemy should the first shots miss. Modern high speeds are no disadvantage in a tail action, since the rate of approach can always be adjusted to give the necessary time (4-5 seconds) for close range shooting. When attacking a bomber, the best position is from the rear, slightly below, either on left or right. The bomber is then passed on the opposite side to which his gun turrets are pointing. The whole art of the fighter is to remain " invisible " as long as possible and carry out the actual attack at short range without the need of sighting corrections. In conclusion, the author raises the important question of obtaining the necessary number of trained pilots to make up for losses in a modern war.

Aerial Vulnerability. (E. Herrera, L'Aérophile, Vol. 47, No. 12, December, 1939, pp. 262-264.) (75/6 France.)

Vulnerability V to air attack of a given territory can be expressed by the following equation :—

$$V = f \Sigma p (d_o - d).$$

f = air power of the enemy.
p = population of each town in the territory considered.
d = shortest distance (km.) of town from the enemy.
d_o = longest distance (km.) over which an effective raid can be carried out.

(This summation can obviously only be carried out if the towns can be defended equally well.)

The author has divided the belligerent countries into zones of constant distance from the enemy frontier and marked the position of all towns with a population above 150,000. Assuming further that the combined air power of France and England is the same as that of Germany and that the methods of defence are also equal, the vulnerability reduces to $p\,(d_o - d)$, where d_o can be put as equal to 1,000 km. Under these conditions the summation gives a vulnerability factor of 94.7 for the Allies against 112.2 for Germany. It is interesting to note that maximum vulnerability in the case of France and England occurs in the London zone (distance 500-600 km.), whilst in the case of Germany the Hambourg and Vienna (distance 400-500 km.) give the highest individual summation.

The following table shows the variation of the vulnerability with distance :—

Zone	0	1	2	3	4	5	6	7	8	9	
Distance in km.	0/100	100/200	200/300	300/400	400/500	500/600	600/700	700/800	800/900	900/1000	
Great Britain and France											
Principal Towns	Strasbourg	—	Lille	Paris	Hull	L'nd'n	Birm'gham	Glasgow	Dublin	—	Total
v	.18	0	1.6	25.4	2.70	37.7	17.1	8.4	1.6	—	94.7
Germany											
Principal Towns	Stutgart	Cologne	Munich	Leipzig	Vienna	Berlin	Breslau	—	—	—	Total
v	5.9	17.5	21.0	11.4	30.1	23.1	3.2	—	—	—	112.2

Some Tactical Episodes in the Polish Campaign. (Flugwehr und Technik, Vol. 1, No. 11-12, Nov.-Dec., 1939, pp. 274-5.) (75/8 Germany.)

(1) The results of all bombing attacks are photographed either from a separate reconnaissance machine accompanying the raiders or from the last bomber taking part in the attack. Only in this way can the effect of the raid be judged and needless repetition avoided.

(2) During the retreat of the Polish armies, bridges found a favourite objective for the bombers. Such bridges were only destroyed when the troops were on the point of crossing. In this way the retreating armies were forced to move in predetermined directions.

(3) The best method of blocking railway lines is to tear up the track by dive bombing immediately in front of a moving train.

(4) By withholding machine gun fire to the last minute and camouflaging the guns, the Poles shot down several low flying bombers. It appears that the small calibre gun is only effective under such conditions of surprise. On the other hand, the Germans claim that in many cases their aircraft withstood successfully direct hits by 2-4 c.m. anti-aircraft shells.

Researches on Steam Turbine Nozzle Efficiency. (H. L. Guy, J.I.C.E., Dec., 1939, pp. 91-124.) (75/9 Great Britain.)

The main lines of research carried out on steam turbine nozzle efficiency, including that due to the Steam Nozzle Committee of the Institution of Mechanical Engineers, are reviewed. Methods of determining the efficiency of nozzles are described; these involve use of a minute pitot tube in a plane parallel to the outlet face of the nozzle, and the use of wind tunnel experiments in which the nozzle specimen is reproduced several times full size so that the " Reynolds number " is maintained at a value of interest in turbine work, but with the low air speeds usual in wind tunnel experiments. A comparison is made of experiments to determine the variation in nozzle coefficient of velocity with steam velocity, and the bearing of these experiments on turbine design is pointed out. The work of J. E. Stanton and J. R. Pannell on flow through rectangular channels is employed to calculate skin friction losses in the nozzle.

Calculation of the Aerodynamic Characteristics of Tapered Wings with Partial-Span Flaps. (H. A. Pearson and R. F. Anderson, N.A.C.A. Report No. 665, 1939.) (75/10 U.S.A.)

Because of the widespread use of tapered wings equipped with partial span flaps, it is desirable to have means for computing their aerodynamic characteristics. The present report presents factors, deduced from aerofoil theory, for use in calculating the induced drag, the angle of zero lift, the pitching moment and the aerodynamic centre of tapered wings with partial span flaps of constant flap chord ratio. The factors are given for wings of aspect ratio 6 and 10, of taper ratios from 0.25 to 1.00, and with flaps of various lengths. The reliability of the theoretical factors was checked against test results obtained with two tapered wings with partial span flaps. In addition, tests were made of three rectangular wings with full span flaps to provide section data for use in calculating the characteristics of the tapered wings. Fair agreement with experimental results was found.

Aerofoil Section Data Obtained in the N.A.C.A. Variable Density Tunnel as Affected by Support Interference and Other Corrections. (E. N. Jacobs and I. H. Abbott, N.A.C.A. Report No. 669, 1939, 32 pp.) (75/11 U.S.A.)

Aerofoil data obtained in the variable density wind tunnel, and published previously by the N.A.C.A. have been known to contain certain consistent errors due to certain corrections not having been applied (*e.g.*, tunnel wall effects, strut support interference, turbulence of the flow). The effect of support interference or aerofoil drag data has now been investigated, tests being made of N.A.C.A. 0012, 0018, 0025, 0030 and 0040 symmetrical profiles to study the variation of support interference with aerofoil thickness. N.A.C.A. 43012, 43018 and 8318 were also tested to investigate the variation of support interference with camber. It is found that previously published data from the variable density tunnel have shown too large drag coefficients and too large a rate of increase of drag coefficient with aerofoil thickness. The practical effect of the corrections on the choice of the optimum sections is briefly considered and corrected data are given for a selected list of aerofoils. Methods of correcting published data for other aerofoils are presented.

A large amount of recent data, however, has suggested that these or other corrections applied to aerofoil data obtained in the V.D. tunnel will not produce ultimately satisfactory results. It is planned, therefore, to obtain further aerofoil section data under test conditions more favourable than those in the V.D. tunnel.

The Wing of Minimum Total Resistance. (H. Reissner, J. Aeron. Sc., Vol. 7, No. 3, Jan., 1940, pp. 114-118.) (75/12 U.S.A.)

As is well known, the wing of minimum induced resistance has an elliptic circulation function.

The author extends the investigation to the case of total resistance (*i.e.*, induced + parasite). The problem is thus to determine the best distribution of induced velocity and the corresponding best lift distribution along the span if the span b, the total lift L, the velocity of flight V and the distribution of drag angle δ are given ($\delta = C_D/C_L$).

The following conclusions are reached:—

1. Minimum total resistance requires that the sum of the induced inflow angle charge and $\delta/2$ should be constant.
2. If δ is constant along the span, the elliptical lift distribution gives both minimum induced drag and minimum total drag.
3. If δ decreases parabolically from the middle of the span to the tips, the circulation distribution for minimum total drag is given by

$$\Gamma = \Gamma_1 \sin \psi + \Gamma_3 \sin 3\psi.$$

4. The more general case of any symmetrical distribution of the drag angle along the span can be solved by means of Fourier's series with sufficient accuracy.

5. From a worked out example it appears that for minimum total drag the elliptic lift distribution must be distributed in the sense of an increase towards the tips (fuller shape) and a corresponding reduction of the maximum circulation.

Effects of Elevator Nose, Gap, Balance, and Tabs on the Aerodynamic Characteristics of a Horizontal Tail Surface. (H. J. Goett, J. P. Reeder, N.A.C.A. Tech. Report, No. 675, 1939.) (75/13 U.S.A.)

Results are presented showing the effects of gap, elevator nose shape, balance, cut-out, and tabs on the aerodynamic characteristics of a horizontal tail surface tested in the N.A.C.A. full-scale tunnel.

The presence of a gap caused an 18 per cent. reduction in the variation of normal force with elevator deflection, but the size of the gap (between 0.005 $\bar{c}$ and 0.010 $\bar{c}$ where $\bar{c}$ = average chord) was an unimportant factor. At small elevator deflections the effectiveness of aerodynamic balance of the elevator in reducing hinge moments was much lower with the tapered nose than with the blunt nose. The tapered nose, however, maintained its effectiveness to much greater deflections and gave a greater maximum normal force increment than did the blunt nose. With the blunt nose, the hinge moments were reduced 30 and 40 per cent. with 10 and 20 per cent. balances, respectively. This reduction is fairly uniform up to the stall of the elevator. The decrease in normal force and hinge moment caused by a cut-out was proportional to the area removed. The variation in tab effectiveness with a change in tab span was found to be approximately proportional to the area moment of the tab about the elevator hinge line. A comparison of the various experimental aerodynamic characteristics with those computed from Glauert's thin aerofoil theory for hinged flaps is also given.

Interference of the Tail Surfaces and Wing and Fuselage from Tests of 17 Combinations in the N.A.C.A. Variable Density Tunnel. (A. Sherman, N.A.C.A. Tech. Report No. 678, 1939.) (75/14 U.S.A.)

An investigation of the interference associated with tail surfaces added to wing fuselage combinations was included in the interference programme in progress in the N.A.C.A. variable density tunnel. The results indicate that, in aerodynamically clean combinations, the increment of the high speed drag can be estimated from section characteristics within useful limits of accuracy. The interference appears mainly as effects on the downwash angle and as losses in the tail effectiveness and varies with the geometry of the combination. An interference burble, which markedly increases the glide path angle and the stability in pitch before the actual stall, may be considered a means of obtaining satisfactory stalling characteristics for a complete combination.

The Radiation of the Acoustic Air Jet Radiator Derived from Observation of the Amplitude of the Aerial Vibrations in the Oscillator. (J. Hartmann and F. Lazarus, Phil. Mag., Vol. 29, No. 193, Feb., 1940, pp. 140-147.) (75/15 Denmark.)

An air jet discharged at supersonic speed is characterised by a series of equidistant sections which are unstable. If a cylindrical oscillator (*e.g.*, a sharp edged cavity in the end of a piece of brass) is arranged with the aperture facing the stream, resonance of the air in the cavity will occur, if the aperture is within one of the unstable sections of the jet. The arrangement is particularly well suited for the frequency range 10^4 to 10^5 cycles/sec. For an excess pressure of 3 atmospheres in the jet, an acoustic output of 6 watts at 5×10^4 cycles and about 160 watts at 10^4 cycles/sec. can be obtained.

In both cases the efficiency is of the order of 4 per cent., *i.e.*, the acoustic output is 4 per cent. of the power theoretically required for maintaining the jet.

The authors have carried out experiments on the total radiation by direct observations of the amplitude of the oscillations in the resonator, using an optical method. (Riemann mirror or shock wave.) The results of the new method are in satisfactory agreement with those obtained with a Rayleigh disc.

Formation of a Vortex at the Edge of a Plate. (L. Anton, Ingenieur Archiv., Vol. 10, No. 6, Dec., 1939, pp. 411-27.) (75/16 Germany.)

The flow around an infinitely broad plate can be represented as a potential flow with surfaces of discontinuity starting off from the plate. By means of a conformal representation it is possible to calculate the velocity field corresponding to a given form of the surfaces of discontinuity and given vortex distribution. A necessary condition is that the velocity must be finite at the edges of the plate. However, this is not sufficient to determine the shape and vortex distribution of the surfaces. Nevertheless, on the basis of a similarity condition, it is possible to find for an infinitely broad plate a solution of this problem which is correct for the first commencement of fluid motion. Setting out from this solution, further development of vortex distribution and shape of the surface is followed up for the case of a plate of infinite breadth.

Observations in Flight of the Region of Stalled Flow Over the Blades of an Autogiro Rotor. (F. J. Bailey, F. B. Gustafson, N.A.C.A. Tech. Note No. 741, December, 1939.) (75/17 U.S.A.)

The flow over the inner halves of the rotor blades on a Kellett YG-1B autogiro was investigated in flight by making camera records of the motion of silk streamers attached to the upper surfaces of the blades. These records were analysed to determine the boundaries of the region within which the flow over the blade sections was stalled for various tip-speed ratios. For the sake of comparison, corresponding theoretical boundaries were obtained. Both the size of the stalled area and its rate of growth with increasing tip-speed ratio were found to be larger than the theory predicted, although experiment agreed with theory with regard to shape and general location of the stalled area. The stalled region may be an important factor in both the rotor lift-drag ratio and the blade flapping motion at the higher tip-speed ratios. The method of study used in this paper should be useful in further studies of the problem, including the reduction of the size of the region.

Contribution to the Aerodynamics of Rotating Wing Aircraft. (G. Sissingh, N.A.C.A. Tech. Memo. No. 921, December, 1939.) (75/18 U.S.A.)

The conventional methods for the mathematical investigation of rotors of rotating wing aircraft with hinged blades are extended and refined.

The chief defect of the investigations up to now was the assumption of a more or less arbitrary " mean " drag coefficient for a section of the blade. This defect is remedied through replacement of the constant coefficient by a function of higher order which corresponds to the polar curve of the employed profile. The treatment includes the twisted rectangular blade and a non-twisted taper blade.

The theory includes all flight stages of rotating wing aircraft from autogiro without power input to helicopter with forward tilted rotor axis without regular propeller, and gives results up to coefficients of advance of from 0.4 to 0.5 which are in satisfactory agreement with wind tunnel tests.

The calculation becomes uncertain when, at higher coefficients of advance, the zone of the separated flow within the rotor area is no longer covered by the stipulated assumptions and the effect of the occasional reversed velocity region, for which the substitute functions for the air force coefficients on the blade element are no longer applicable, is observed as interference.

Shoulder Safety Belts. (Sci. Am., Vol. 162, No. 2, Feb., 1940, p. 98.) (75/19 U.S.A.)

Records of accidents suffered by Air Corps pilots recently revealed a larger number of injuries to the head and face than to other parts of the body. The reason is that the lap type safety belt prevents the lower part of the body from being thrown forward; in case of a crash, the upper part of the trunk and the head are unrestrained and jack-knifed forward and the head strikes the instrument panel or other structural parts of the aeroplane. To meet this situation the Material Division of the Army Air Corps has developed a shoulder type safety belt.

If service tests are as favourable as experimental tests, the shoulder belt will become standard Air Corps equipment with added safety for U.S.A. pilots.

The Influence of Running Propellers on Aeroplane Characteristics with Discussion. (C. B. Millikan, J. Aeron. Sci., Vol. 7, No. 3, Jan., 1940, pp. 85-106.) (75/20 U.S.A.)

As is well known, the propeller slipstream exerts a powerful effect on the static and directional stability of an aircraft as well as on $C_{L\ max}$.

The only satisfactory method of investigating these effects in the wind tunnel is to carry out experiments with models fitted with running propellers. The author describes the equipment of the California Institute of Technology (Calcit), paying special attention to the induction motors employed for the propeller drive. These motors employ three-phase alternating current of frequency up to 300 cycles and deliver 5 h.p. at 18,000 r.p.m., the outside diameter being $3\frac{3}{4}$in. and the length (excluding propeller shaft) $6\frac{5}{8}$ in. The power absorbed is measured electrically after calibration on a special dynamometer. The speed of rotation is obtained by matching on an oscilloscope the alternating current from a magnetic pick-up on the motor shaft against a saw tooth current wave produced by a variable speed commutator, the speed of which is measured directly with a Jaquet indicator. The aircraft model utilised has a span of the order of 7 feet. The author gives details of the experimental procedure adopted and concludes by emphasising the need of correlating the results obtained in various laboratories. In the discussion, the need for extending the experiments to include counter rotating propellers and more full-scale experiments is emphasised.

Vibration of Crankshaft Propeller Systems (New Method of Calculation). (M. A. Biot, J. Aeron. Sci., Vol. 7, No. 3, Jan., 1940, pp. 107-112.) (75/21 U.S.A.)

The calculation of torsional oscillation in crankshaft propeller systems is carried out by a new method which reduces considerably the numerical work in the case of in-line engines. The theory is briefly outlined and the reader is referred to another publication of the author for further details. Three applications follow. In the first, all six natural frequencies and the corresponding modes are calculated for a V-12 engine. In the second example the method is adapted to the direct determination of the fundamental frequency. The third example deals with a 12-cylinder flat opposed engine coupled to a blower and through gears to a propeller; all eight natural frequencies are determined. The natural frequencies are determined by plotting a simple curve generally close to a straight line and the corresponding modes of oscillation in the crank are expressed in terms of a sine function. The amount of numerical work involved in the procedure is independent of the number of cylinders of the engine.

Second Annual Rotating Wing Aircraft Meeting. (J. Aeron. Sci., Vol. 7, No. 3, Jan., 1940, pp. 120-121.) (75/22 U.S.A.)

Short digests of the following papers are given:—

Army Experience with Rotary Aircraft (E. S. Nichols).

Rotor Craft Drive Systems (J. M. Shuckers).

New Parameter for Lifting Rotors (A. M. Young).
Roof Landing Problems (J. M. Miller).
Commercial and Military Uses of Rotating Wing Aircraft (I. Sikorsky).
Economic Significance to Passenger Traffic of Central City Landings (C. E. McCollum).
Mechanical Design on Rotary Aircraft (J. S. Pecker).
Gyroplanes and Combination Types (E. B. Wilford).
Performance Losses on Rotors with Centre Cut-Outs (P. H. Stanley).
Span Analysis of Rotor Blades (H. Mulvey).
Photographic Observations in Flight of the Stalling of Rotor Wings (F. T. Bailey).
Rotor Controls (H. S. Campbell).
Frequency and Vibration Problems of Rotors (R. H. Prewitt and R. A. Wagner).
Notes on Autogiro Rotor Longitudinal Stability (A. Klemin and others).

(See Abstracts 75/23 to 75/30.)

Army Experiences with Rotary Aircraft. (E. S. Nichols, Second Annual Rotating Wing Aircraft Meeting, J. Aeron. Sci., Vol. 7, No. 3, Jan., 1940, p. 120.) (75/23 U.S.A.)

The author described experiments demonstrating the effective use of autogiros for: (1) Direct wire telephone communication with ground crews; (2) use near the front lines where the small space required for take-off and landing makes their concealment relatively easy; (3) conducting troops on the march. It was concluded by the author that the autogiro is capable of defending itself against attacking aeroplanes from all sides except possibly from overhead attack. Their military use would be enhanced by improved roadability to facilitate their movement over the ground.

New Parameter for Lifting Rotors. (A. M. Young, Second Annual Rotating Wing Aircraft Meeting, J. Aeron. Sci., Vol. 7, No. 3, Jan., 1940, p. 120.) (75/24 U.S.A.)

The author described his experiments with rotors in which the tendency of the rotor to tip when its support was tipped was considered as the important factor determining whether or not the rotor was stable. The new parameter mentioned in the title was the " tipping factor," or the extent to which tipping of the rotor affects the angle of attack of a blade which is perpendicular to the plane in which the rotor is tipped. In the model tests the rotor with a tipping factor of zero (blades hinged at hub) was unstable while that with a tipping factor of unity (rotor mounted on a universal joint) was stable. The latter type was unstable in a wind. A rotor with a tipping factor of 0.5 was stable both in a wind and in still air.

Gyroplanes and Combination Types. (E. B. Wilford, Second Annual Rotating Wing Aircraft Meeting, J. Aeron. Sci., Vol. 7, No. 3, Jan., 1940, p. 121.) (75/25 U.S.A.)

The various types of gyroplanes and combination types were compared, including (1) Cierva (hinged blade with tilting axis control), (2) Hafner (hinged blade with feathering control), (3) Herrick (rigid rocking blade with rotor control), and (4) Wilford (semi-rigid blade with feathering control), on the basis of ruggedness, ease of balance, positiveness of control and reduction of control forces, stability in flight, and other factors. Each type was given a " figure of merit " based on the author's engineering judgment. Helicopters with single rotor, two coaxial rotors, and two side-by-side rotors were treated in a similar manner. Finally, combination types of autogiro, helicopter, and aeroplane were described and were considered to be a promising type.

Treatment of Performance Losses on Rotors with Centre Cut-Outs. (P. H. Stanley, Second Annual Rotating Wing Aircraft Meeting, J. Aeron. Sci., Vol. 7, No. 3, Jan., 1940, p. 121.) (75/26 U.S.A.)

The paper described efforts to eliminate the detrimental losses around the root-ends of the blades and at the hubs of autogiros. First attempts comprised fitting a lenticular covering of porous elastic fabric around the hub. This was found to be unsatisfactory. A second fairing, of sheet metal, covered with porous fabric, increased the top speed by 1 m.p.h. and cut down the rotational speed from 144 to 131.5 r.p.m. Analysis indicates that if the gross weight had been changed to bring the tip speed ratios of the faired and unfaired rotors to the same value at high speed, a greater advantage would have been shown for the faired rotor. The author recommends a fairing of rubberised fabric around the hub extending to the blade root-ends; the lenticular shape would be maintained by air bladders inside the fairing. The performance of blades running through the hub and those that end outboard of the hub and the effect of solidity were considered.

Photographic Observations in Flight of the Stalling of Rotor Wings. (F. J. Bailey, Second Annual Rotating Wing Aircraft Meeting, J. Aeron. Sci., Vol. 7, No. 3, Jan., 1940, p. 121.) (75/27 U.S.A.)

The author described recent experiments at Langley Field in the wind tunnel and in flight. The wind tunnel experiments on l/d as a function of the tip speed ratio led to an optimum tip speed ratio of 0.35. The angles of attack of the blades were calculated for all points on the disc and compared with the stalled area determined in flight. A camera was mounted at the hub pointing along a blade; motion pictures of wool tufts attached to the blade were taken and analysed. The stalled region was slightly larger than that calculated. The moving pictures were shown. It was concluded that the stalling angle of the blades of an autogiro should be greater than 15°.

Rotor Controls. (H. S. Campbell, Second Annual Rotating Wing Aircraft Meeting, J. Aeron. Sci., Vol. 1, No. 3, Jan., 1940, p. 121.) (75/28 U.S.A.)

For attitude control the following two systems appear equivalent as far as aerodynamic characteristics and control loads are concerned. (*a*) Flapping pivots through centre of rotation with pitch control. (*b*) Flapping pivots through centre of rotation with tilting control fulcrums centred at plane of rotation. Tilting control has the following advantages: (*a*) Absence of torsional inertia blade loads in the controls. (*b*) In designs where pivot offsets do not create excessive control loads—simplicity of design for hub and control parts. (*c*) Adaptability for use with blade mountings on angular pivots to provide pitch change responsive to torque, left effects, over-speeding, etc. (*d*) Freedom from vibrations arising from torsional motion of the blades. Among the advantages of feathering control systems are listed the following: (*a*) For use in heavy machines having considerable offset of the flapping pivots. (*b*) For control systems in which simultaneous pitch change is desired under operating conditions which cannot be readily reduced to simple automatic actuation. (*c*) For rotors which are intended to be used on different machines having widely different design characteristics. By modifying the control hook-up different characteristics may be imparted to the same rotor system.

Frequency and Vibration Problems of Rotors. (R. H. Prewitt, R. A. Wagner, Second Annual Rotating Wing Aircraft Meeting, J. Aeron. Sci., Vol. 7, No. 3, Jan., 1940, p. 121.) (75/29 U.S.A.)

On the basis of a theoretical investigation the following conclusions were drawn: (1) With normal vertical pin locations, and without additional centring springs, the natural pendular frequency of the blade about the vertical pin is from one-third

to one-fifth the rotor speed. (2) With additional specialised centring means, the natural pendular frequency of rotor blades may be made to vary with amplitude of oscillation. (3) The natural flapping frequency of a rotor blade with the flapping axis perpendicular to the blade and located on the axis of rotation, neglecting damping, is equal to the rotor r.p.m. (3*a*) Moving the flapping axis outboard increases that natural frequency in a normal design roughly $2\frac{1}{2}$ per cent. (3*b*) Average coning of the blade reduces the basic natural frequency in a normal design roughly 3 per cent. (3*c*) Damping reduces the basic natural frequency approximately 15 per cent. with the flapping axis perpendicular to the blade. (3*d*) Cocking the horizontal hinge toward the leading edge of the blade has the effect of increasing the value of the damped natural frequency with increases in the angle of cocking. (4) The natural bending frequency in the plane of flapping depends so much upon the structure of the blade that no one value can be given for this term. The natural bending frequency in the plane of rotation for a plywood covered blade having a chord of 1 ft., a radius of 20 ft., and a 17 per cent. thickness ratio, at 200 r.p.m. of the rotor, is approximately $2\frac{3}{4}$ times the rotor speed.

Notes on Autogiro Rotor Longitudinal Stability. (A. Klemin, V. R. Haugen, S. B. Sherwin, Second Annual Rotating Wing Aircraft Meeting, J. Aeron. Sci., Vol. 7, No. 3, Jan., 1940, p. 121.) (75/30 U.S.A.)

To clear up the disagreement between experimenters with and designers of autogiros, the authors carried out a theoretical investigation and arrived at the following conclusions: (1) For a rotor with offset hinges, with moments referred to the centre of the rotor, there is always a stalling moment; (2) the thrust moment may be positive or negative depending on the character of the flapping motion, but the inertia moment is so much greater that it determines the sign of the resultant moment; (3) the stalling moment increases with the tip speed ratio, and the centre of pressure moves forward with increased angle of attack, *i.e.*, the rotor is inherently stable.

Cooling on the Front of an Air-Cooled Engine Cylinder in a Conventional Engine Cowling. (M. J. Brevoort, U. T. Joyner, N.A.C.A. Tech. Report No. 674, 1939.) (75/31 U.S.A.)

Measurements were made of the cooling on the fronts of model cylinders in a conventional cowling for cooling in both the ground and the cruising conditions. The mechanisms of front and rear cooling are essentially different. Cooling on the rear baffled part of the cylinders continually increases with increasing fin width.

For the front of the cylinder, an optimum fin width was found to exist beyond which an increase in width reduced the heat transfer.

The heat transfer coefficient on the front of the cylinders was larger on the side of the cylinder facing the propeller swirl than on the opposite side. This effect became more pronounced as the fin width was increased. These results are introductory to the study of front cooling and show the general effect of the several test parameters.

100 *Octane Fuel in the U.S.A.* (Les Ailes, No. 962, 4/1/40, p. 5.) (75/32 U.S.A.)

American refineries have taken steps to be soon in a position to produce 100 octane fuel at the rate of 40 million tons a month.

The present daily production of some of the larger refineries amounts to from 100 to 200 tons, whilst many smaller plants produce from 10 to 30 tons daily.

The selective refining processes adopted utilise either phosphoric or hot sulphuric acid. It is stated that more that 200 million dollars have been recently invested in developing the industry for large scale production of 100 octane fuel. Apart

from its employment in aero engines, it is thought that a further field of application of this high grade fuel will ultimately be found in road transport.

Some Remarks Regarding the Testing of Engine Lubricants. (C. A. Bouman, J. Inst. Petroleum, Pol. 25, No. 194, Dec., 1939, pp. 771-8.) (75/33 Great Britain.)

This paper is mainly concerned with investigation of the high temperature stability of lubricants. Oxidation tests are unable to represent the various processes of deterioration taking place in the engine, since temperatures and other conditions vary from place to place in the engine so that oils are not rated in the same order of merit for all of them. The application of results of laboratory tests should be restricted only to a certain number of the processes taking place in the engine, the test temperatures having been adjusted as closely as possible to those existing in the parts of the engine in which the reactions under consideration occur. Deterioration of crankcase oil due to contamination by products from incomplete combustion cannot be correctly ascertained from laboratory tests.

Carbon tests are of some value with regard to carbon formation in the combustion space, but not with regard to carbon formation in piston ring grooves or tendency to ring sticking. In the latter case engine testing is the only way to obtain reliable results, and even then the degree of reproducibility is often too small to allow sound conclusions to be deduced from a few tests. Since test results depend so much on mechanical conditions in the engine, engine lubricating oil tests should in general be of a comparative nature, especially when the effect of dopes has to be studied.

Motor Methods of Testing Fuels and Lubricants. (A. Von Philippovich, Oel u. Kohle, Vol. 15, 1939, pp. 551-6.) (75/34 Germany.)

The C.F.R. motor method of knock rating is criticised and suggestions are made for improving its usefulness. To determine the instant at which knocking starts it is essential to have an automatic indicator, preferably recording the second differential of the pressure with respect to time. Octane numbers should be determined with the mixture temperature at 86°F., 122°F. and 212°F., as well as at the standard temperature of 300°F. From these figures diagrams can be drawn showing variation in octane number with temperature. The diagrams thus obtained are of four types:—1, Aromatic; 2, olefinic; 3, alcohol mixtures; 4, paraffinic. It is therefore suggested that in reporting the octane number of a fuel the appropriate suffix should be used, *e.g.*, O.N. 73_2 signifies an octane number of 73 having a temperature variation of the olefinic type. This will enable a more accurate forecast to be made of the behaviour of a fuel in an engine.

For the testing of lubricating oil actual engine tests are again preferable. A useful method is to determine the time required for ring-sticking to occur in an engine run under fixed conditions at different temperatures. This gives an idea of the stability of oils at different temperatures, and thus the most suitable oil for use in any particular engine whose working temperature is known can be deduced.

Viscosity Index of Lubricating Oils. (E. W. Dean, A. D. Bauer and J. H. Berglund, Ind. and Eng. Chem. (Ind. Edition), Vol. 32, No. 1, Jan., 1940, pp. 102-107.) (75/35 U.S.A.)

The viscosity index of an oil is defined by the equation:—

$$VI = \{ (L-U)/(L-H) \} \times 100$$

when U = viscosity of oil at 100°F. and L and H are basic constants representing viscosity at 100°F. of hypothetical oils having the same viscosity at 210°F. as the oil in question at the same temperature.

By definition hypothetical oil L has a viscosity index of zero and hypothetical oil H one of 100.

Originally, L and H oils approximated to actual blends representing extreme types of commercial lubricating oils available at the time the viscosity index scale was first proposed (1929). The scale has now been defined more accurately by a series of equations connecting the viscosity at 100°F. with that at 210°F. for both L and H.

If, therefore, the viscosity of an oil at 210°F. is known, L and H can be obtained from tables and the viscosity index follows from the above equation after substituting for U.

The greater VI the less does the oil thicken on cooling from 210°F. to 100°F. At the same time, for the same VI, the ratio of the viscosity at 100°F. to that at 210°F. is the greater the higher the viscosity at 210°F. This is shown in the following tables:—

$VI = 100$.		$VI = 0$.	
η 210°F.	η 100°F. (centistokes).	η 210°F.	η 100°F. (centistokes).
10	88	10	155
8	63.5	8	110
6	40.5	6	62
4	20.5	4	26.7

A high viscosity index is of value if the oil has to function satisfactorily over a large temperature range. Apart from engine lubrication, the factor is thus of importance in determining the suitability of an oil for Oleo landing gears as well as for machine gun lubrication.

Experience has shown that the viscosity index of an oil depends mainly on the origin of the crude, and the index will thus also be of use for specification purposes.

Gum Formation in Cracked Gasolines. (D. L. Yabroff, E. L. Walters, Ind. and Eng. Chem. (Ind. Edition), Vol. 32, No. 1, Jan., 1940, pp. 83-88.) (75/36 U.S.A.)

The formation of gum during the induction period of cracked gasolines has been found to proceed at a simple exponential rate at elevated temperatures. The time required for a gasoline to reach a gum content of 10 mg. per 100 ml. (designated as the 10-mg. gum time) is affected by temperature and oxygen pressure in essentially the same manner as is the induction period. The 10-mg. gum time can accordingly be extrapolated to storage conditions, which allows a prediction of the storage life of the gasoline.

The Influence of Various Lubricants on the Seizure Characteristics of Hard Steel and Bronze. (D. Clayton, Engineering, Vol. 149, No. 3865, 9/2/40, pp. 131-5.) (75/38 Great Britain.)

The experiments described show that both lubricant and metal play an important part in determining behaviour as regards both wear and seizure. With steel balls the oil provides a large measure of protection in the low-load range; some wear of a very fine kind occurs and is probably kept low by the partial boundary films of lubricant. With water, boundary film of the same kind is not formed and fine wear takes place to a greater extent. The protection afforded by mineral oil appears as a disadvantage when seizure loads are reached, since more severe cohesion occurring has worse results. The thin liquids have some relatively beneficial quality at this stage, possibly due to their better cooling effects. When a steel ball rubs on bronze balls the yield by the softer material is of considerable importance. Very high loads can be taken without seizure and the lubricant has little effect, possibly because the yielding has allowed a fluid film to form. The thin liquids are exceptional and affect the cohesion, as loss of material occurs at all loads with water, compared with comparatively little with petrol over a considerable range. The relative wear of rotating and stationary balls depends on the material and with bronze and steel together the lubricant affects the bronze,

picking up fine steel particles which, in continued running would probably have a lapping action.

The Static Friction of Lubricated Surfaces. (A. Fogg and S. A. Hunwicks, J. Inst. Petrol., Vol. 26, No. 195, Jan., 1940, pp. 1-18.) (75/37 Great Britain.)

For carrying out these experiments the author modified the standard Deely machine by substituting $\frac{1}{2}$ in. steel balls for the flat pegs and also introduced a new method for cleaning the metal surfaces (removal of surplus oil with trichlorethylene vapour and subsequent rubbing with finest grade emery paper—0000 blue black).

The following substances were investigated for static function over the temperature range 20°C.—100°C. :—

(1) Fatty oils.
(2) Mineral oils.
(3) Extreme pressure lubricants.
(4) Graphited oils.
(5) Compounded oils.
(6) Common liquids.

The average results are given in the following table:—

Substance	Static Friction coefficient 20°C	100°C	Remarks
Fatty oils	0.10	0.10	Good repeats—practically no temperature effects.
Mineral oils	0.15	0.20	Consistency not so good
Extreme pressure lubricants ...	0.10	0.10	Good repeats.
Graphited oil	0.13	0.15	After graphite has worked into surface (time lag).
Oil (10 per cent. oleic)	0.14	0.14	(Parent oil 0.15 and 0.20.)
Glycerine	0.20	0.25	Consistent results.
Trichlorethylene	0.33	—	Very consistent results.
Alcohol	0.43	—	Consistent results.
Benzene	0.48	—	Variable results.
Minimum oiliness, steel on steel...	0.58	—	After abrasive cleaning. Consistent results.

From the above, it appears that the class of ordinary lubricants range from 0.08 to 0.20 in static coefficient of friction. It will be noted that extreme pressure lubricants have practically the same static friction coefficient as fatty oils. Yet the latter fail under the working condition of extreme pressure lubrication. The ability to prevent seizure under extremely high pressures is generally attributed to some chemical action between the active constituent of the oil and the metal. The experiments of the author, however, show conclusively that even if a new surface layer is formed under these conditions, it does not affect the coefficient of static friction.

A further point of interest is the behaviour of graphited oils. Here the experiments definitely show a reduction in static friction due to the graphite working into the metallic surfaces. The effect takes some time to develop and persists if the lubricant is replaced by a plane oil (ungraphited).

A Two-Load Method of Determining the Average True Stress-Strain Curve in Tension. (C. W. MacGregor, J. App. Mech., Vol. 6, No. 4, Dec., 1939, pp. 156-8.) (75/39 U.S.A.)

A method developed at the Massachusetts Institute of Technology is described, whereby the complete average true stress-strain curve in tension may be deter-

mined for a material from the beginning of yielding up to fracture under ordinary testing speeds by the observation during the test of only two loads applied to a tapered specimen, namely, the maximum and fracture loads. Diameters at various positions along tapered specimens are measured before and after the test, and stress and reduction-of-area values are computed from these observations.

Adaptation of Electric Motors to the Drive of Machine Tools. (J. Roy, Electricité, Nov., 1939, pp. 327-34. Met. Vick. Tech. News Bull., No. 691, 29/12/39, p. 8.) (75/40 France.)

The author first discusses the question of motor frames, their ventilation and methods of fixing, following which he deals with A.C. motors dealing with electrical protection, choice of motor, slow running, reversal, electrical braking, speed regulation, multipole motors, speed reducing and varying mechanisms. He then briefly considers D.C. motors, and in conclusion gives a number of examples of electrical drives.

The Protective Effect of a Cladded Layer with Additional Surface Protection in the Case of an Aluminium-Copper-Magnesium Alloy. (W. Geller, Zeit. für Metallkunde, Vol. 31, No. 12, Dec., 1939, pp. 365-6.) (75/41 Germany.)

The effect of an additional surface protection on the long period protective action of a cladded layer of pure aluminium or an alloy of the Al-Cu-Mg type has been investigated. It was found that the long-period protective effect only remains intact in the case of slight damage to the cladding; with greater damage it is completely lost. An additional surface treatment as a protection against corrosion is therefore advisable only if the cladded layer as such will not withstand attack, or if the type of corrosion present does not permit a long-period protective effect on the part of the layer of cladding.

X-Ray Stress Measurement without Use of a Calibrating Substance. (A. Thum, K. H. Saul and C. Petersen, Zeitschrift für Metallkunde, Vol. 31, No. 12, December, 1939, pp. 352-8.) (75/42 Germany.)

A new method is described for obtaining accurate reflection photographs, required particularly for X-ray measurement of elastic stresses; the distance between the camera and the test piece, instead of being measured by simultaneously photographing the interference rings of a calibrating substance, is measured by an " artificial line " produced by scattered radiation. It is shown that a cylindrical camera has many advantages over the flat camera previously used. All the formula necessary for evaluating the photographs are summarised. Examples of the application of the method are described; the accuracy obtained in a measurement made on steel is stated to be ± 0.5 kg./mm. in the best case.

Ignitron Contactor Control of Resistance Welding. (W. C. Hutchins, G.E. Rev., Dec., 1939, pp. 544-7.) (75/43 Great Britain.)

This article describes the operation of the ignitron contactor for the control of resistance welding. Design details of a number of contactor panels are given, and graphs of the tube rating plotted against duty cycle illustrate the performance of this type of equipment. Water-cooling requirements are described.

Dynamic Fatigue Life of Rubber. (S. M. Cadwell and others, Ind. and Eng. Chem. (Analytical Edition), Vol. 12, No. 1, 15/1/40, pp. 19-23.) (75/44 U.S.A.)

Dynamic fatigue is the gradual deterioration and rupture of a rubber member due to mechanical vibrations imposed on it. The number of repeated mechanical vibrations required to rupture the rubber member is referred to here as the dynamic fatigue life of the member for that particular condition of vibration.

Mention has been made in the literature (1-5) that the dynamic fatigue life of rubber in extension is less when the minimum of the oscillation cycle falls near zero strain; but heretofore no complete study has been published. The fatigue lives of rubber as a function of the oscillation stroke are examined for minimum distortions varying from high compressions through all possible elongations.

The general dynamic fatigue characteristics of rubber in linear vibration in a dark, dry enclosure are (L_{min} = minimum length during the vibration; L_o = free unstrained length): (1) For a given oscillation stroke the dynamic fatigue life is a minimum when $L_{min} = L_o$; (2) for a constant value of L_{min} the dynamic fatigue life decreases as the oscillation stroke increases; (3) for given strain limits of oscillation the dynamic fatigue life is usually lower the harder the stock; (4) the dynamic fatigue life depends to a large degree on the rubber temperature.

The dynamic fatigue life of rubber worked in shear can be related to the dynamic fatigue life of rubber vibrated through linear strains.

Magnesium Castings Used in Germany. (Metal Progress, Vol. 37, No. 1, Jan., 1940, pp. 63, 78, 82 and 84.) (75/45 U.S.A.)

Since Germany has ample raw materials for the preparation of magnesium and its alloys, it is only natural that great attention has been given to this metal. It appears that casting alloys have been used to a much greater extent than forgings or extensions.

Three families of alloys, with Al, Si and Mn respectively are most favoured. The suffixes indicate the approximate percentage.

Al Series.

$\left.\begin{array}{l} Mg\text{-}Al_{10}\text{-}Zn_5 \\ Mg\text{-}Al_6\text{-}Zn_3 \\ Mg\text{-}Al_4\text{-}Zn_3 \\ Mg\text{-}Al_3\text{-}Zn_1 \end{array}\right\} + 0.5\%$ Mn.

Si Series.

$Mg\text{-}Si_2$ (for liquid tight castings).

Only the 10 per cent. Al alloy is heat treated (annealing alone or together with temper hardening). This raises the ultimate strength of the casting from an original value of about 25,000 lb. per sq. in. to a maximum of 40,000 lb. per sq. in., together with a corresponding increase in hardness.

Casting alloys are generally free from stress corrosion. Corrosion resistance is increased by treatment with a nitric acid-alkali-bichromate pickle. Varnish is the best protection at the present time.

As a result of its elastic behaviour, magnesium alloy constructions are not very sensitive to sudden blows and they possess great capacity to absorb work.

Their power to absorb noise is useful for gear housings.

The Oscillations of a Gyroscope Electrically Coupled with a Mass. (K. Magniss, Z.V.D.I., Vol. 83, No. 6, 11/2/39, p. 155.) (75/46 Germany.)

In all technical gyroscopic problems, the gyroscope is connected with certain masses which are either part of the instrument or necessary for the support of the gyro. In order to allow for this coupling, the ordinary equation of the gyroscopic motion must be supplemented by a set taking into account the oscillations.

As an example, a single gyroscope suspended in gimbals has three degrees of freedom and in the case of a rigid axis it may carry out two kinds of oscillations: A rapid oscillation in nutation and a slow oscillation in precession. If the shaft is elastic, two further kinds of oscillation are possible and both the nutation and precession are affected.

The greater accuracy required of modern gyroscopic instruments requires these effects to be considered, as otherwise objectionable resonance phenomena may arise.

In the discussion, the introduction of an " apparent " directional couple and an " apparent " moment of inertia in the calculation are recommended. The precession frequency is calculated from the true directional couple and the apparent moment of inertia, whilst the frequency in nutation follows from considerations of the " apparent " directional couple and the true moment of inertia. By the introduction of these concepts the mathematical equations are considerably simplified.

The Application of Complex Mathematics to Gyroscope Theory. (L. Stellmacher, Z.V.D.I., Vol. 83, No. 6, 11/2/39, p. 155.) (75/47 Germany.)

When investigating small stable motions carried out by a gyroscopic system about a position of equilibrium, the problem is simplified by introducing the complex co-ordinates $\alpha + i\beta = z$ when α and β are the angles which the axis of the system makes with the true vertical. The simplification is especially marked in all cases when the gyroscopes are symmetrically suspended with regard to their two degrees of freedom and are subjected to symmetrical moments about the two corresponding axes.

The method can, however, also be applied if a small departure from symmetry exists and is especially useful in all problems involving coupling and damping.

In the discussion, it was pointed out that in the case of two-dimensional problems, the position locus as well as the time should also be expressed in complex form.

Since the functional relationship and integration of two complex functions has already received considerable attention, it is often possible to integrate differential equations and thus obtain a solution to a gyroscopic problem which could only be solved with great difficulty if real co-ordinates are employed.

A Mechanical Harmonic Synthesizer-Analyser. (S. L. Brown, J. Frank. Inst., Vol. 228, No. 6, Dec., 1939, pp. 675-694.) (75/48 U.S.A.)

A harmonic synthesizer is described that has thirty harmonic elements (fifteen sine components and fifteen cosine components) that operate simultaneously, and the sum of the thirty sinusoidal movements is recorded by a tracing point (pencil) on a drawing board that is driven uniformly past the pencil point.

Analysis is accomplished by setting the amplitudes of the thirty elements to values that are determined from the values of selected ordinates from the curve to be analysed and the harmonic components of this curve are determined from selected ordinates of the auxiliary curve that is traced by the machine. Thirty-two equi-spaced ordinates from the curve to be analysed furnish sufficient data whereby analysis is accomplished by a single trace of the machine, that includes fifteen harmonic components (fifteen sine components and fifteen cosine components), or sixty-four equi-spaced ordinates may be taken from the curve and the analysis will include thirty-one harmonic components that are obtained from two traces made by the machine (odd harmonics are determined from one auxiliary curve and even harmonics from the other curve); or, one hundred and twenty ordinates may be selected from the curve and the analysis is extended to fifty-nine harmonic components by tracing four auxiliary curves with the machine.

Industrial Research in 1939. (W. A. Hamor, Industrial and Engineering Chemistry (News Edition), Vol. 18, No. 1, 10/2/40, pp. 1-13.) (75/49 U.S.A.)

In 1939 over 30,000 scientists and engineers with about half that number of assistants and clerical grades were engaged in research in the U.S.A., the total expenditure being of the order of 200 million dollars. The principal results were achieved in organic chemistry, moulding fuels, textile fibres and plastics. The latter have received much attention by the military authorities and the following applications, definite and potential, of these new products are noted:—

(1) Laminated plastics for aircraft construction.
(2) Guide lines, made of cast resins, on aircraft carriers.
(3) Luminescent resins.
(4) Tinted cellulose acetate windows for A.R.P. of gum stocks made from cellulose acetate and fabric filled phenolic resins.
(5) Shaped cellulose acetate sheet as a chute for conveying ammunition belts from ammunition boxes to machine guns on aircraft.
(6) Phenolic resins for mouthpieces and containers for gas masks.
(7) Use of Koroseal plastics in gas masks as a protection against mustard gas.
(8) Use of phenolic resins in the construction of the noses of A.A. shells.
(9) Possible use of synthetic textile Nylon as a parachute material.

The Testing of Loud Speakers. (R. Vermeulin, Philips Tech. Rev., Dec., 1939, pp. 354-363.) (75/50 Great Britain.)

To judge the quality, and to compare different loud speakers, it is desirable to make use of quantitative data, such as the distortion and the frequency characteristics. Methods used in the Philips laboratory for rapid determination of these factors are described; the fundamental problem of the conditions under which the measurements on the loud speaker must take place is also discussed. Measurement of the direct sound alone as well as measurement of the total sound radiation are considered; a measurement in which a certain combination of direct and indirect sound is used as a basis.

Report on Circuit Design for Low Frequency Radio Ranges. (D. M. Stuart, Civil Aeronautics Authority, Report No. 8, 1939.) (75/51 U.S.A.)

This report presents a discussion of the circuit theory involved in the design of the radio range coupling system, and a description of the equipment employed in the latest type of radio range station. Particular emphasis is laid upon the theory of the coupling system because it is the most important part of the entire equipment, and also because its function is perhaps the least understood by those who do not have direct contact with the problems of radio range operation. Some of the theoretical work is new as far as the literature on the subject is concerned, and the results are presented here for the first time in published form.

LIST OF SELECTED TRANSLATIONS.

NOTE.—Applications for the loan of copies of translations mentioned below should be addressed to the Under-Secretary of State (R.T.P.), Air Ministry, Dept. Z.A., London, W.C.2, and will be supplied as far as availability of stocks permit. Suggestions concerning new translations will be considered in relation to general interest and facilities available.

Lists of selected translations have appeared in this publication since September, 1938.

THEORY OF ARMAMENTS.

TRANSLATION NUMBER AND AUTHOR.		TITLE AND JOURNAL.
1004	Bruno, G.	*Calculation of the Trajectory of a Projectile; a New Accurate and Rapid Method.* (Riv. di Artiglierio e. Genio, Vol. 15, 1937, pp. 1331-1368). (R.D. Translation No. 717.)

AERO AND HYDRODYNAMICS.

987	Possio, C.	*Aerodynamic Forces on a Lifting Surface in Oscillatory Motion.* (Turin Polytechnic Aeronautical Laboratory Report, No. 117, Oct., 1938, XVI.)
991	Possio, C.	*Unsteady Motion of an Aerofoil.* (Turin Polytechnic Aeronautical Laboratory Report, No. 121, March, 1939, XVII.)
998	Castagna, A. ...	*Formulæ for the Experimental Study of the Transformation of Energy in a Gas Flowing in a Tube.* (Proc. Roy. Acad. Science, Turin, Vol. 70 (1934-35), pp. 46-51.)

ENGINE ACCESSORIES.

1002	Metral, A.	*The Szydlowski-Planiol Centrifugal Supercharger.* (L'Aeronautique, Vol. 20, No. 235 (Supplement), Dec., 1938.)

MISCELLANEOUS.

941	Zimmerman, E. ...	*Measurements of Pressure Drop in Steam Pipes.* (V.D.I. Lectures, Berlin, 1936, "Prufen und Messen," pp. 76-9.)

MATERIALS.

1000	Borstel, W.	*Spot Welding in Aircraft Construction.* (Junkers Nachrichten, Vol. 9, No. 7, July, 1938.)
1003	Nissen, O.	*Questions of Strength in Aircraft Construction.* (Jahrbuch der Deutschen Luftfahrtforschung, 1938, Supplementary Volume, pp. 158-163.)

REVIEWS.

WIND, SAND AND STARS. Antoine de Saint Exupery.

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" Saint Ex " was the fortunate and worthy companion of the early heroes of the original French North African and finally the South Atlantic lines, who with indomitable perseverance and courage won through to victory in spite of insufficient means and poor material. The route that they conquered is, alas, now marked with their known and unknown resting places, but the lesson they left—of endeavour and victory—is set down in the pages of this book. The tales of the adventures of Guillaumet and Mermoz—that Paladin of the air—are epics, as is also the story of the author's own drama when lost in the Arabian desert.

It may seem a somewhat curious analogy that this man of the air should tell us in his book—" . . . It is man and not flying that concerns me most. . . ."

He might have gone further and said that he whose daily task it has been to risk and face death was more concerned with life, for every line of his book breathes " Joie de vivre " and the satisfaction that he has obtained from wrestling with difficulties. It is good and comforting to know that such men still do and ever will exist.

This fine book has been finely translated in a way which fully preserves the spirit and flavour of the original.

MECHANICS APPLIED TO VIBRATIONS AND BALANCING.

D. Langhorne Thornton, M.A., M.I.Mech.E., M.Inst.C.E., M.I.Mar.E., M.Con.E. Chapman and Hall. 36/- net.

This book is an ambitious essay to encompass within two covers the sum total of knowledge of mechanical vibrations, and the author is entitled to consideration for attempting to perform so monumental a task. The scope of the work may be judged by the chapter headings:—*Balancing of engines, balancing of locomotives, theory of vibrations, progation of stress in elastic materials, beams and plates, rotating shafts and discs, general survey.*

In his preface the author states that the book was written primarily for engineers, and he stresses the advantages of the employment of Lagrange's equations of motion for the solution of practical dynamical problems. In this connection it may be relevant to quote the late Sir George Greenhill:—*

* On the whirling and whip of a revolving shaft. R. & M. No. 560 (Advisory Committee for Aeronautics, 1919).

" His treatment is based on Lagrange's equations of motion, a method which appears to-day to be considered safe to entrust to the mathematical novice. . . . But this analytical method is a delicate sharp tool, and apt to cut the fingers of the inexperienced beginner; even Lagrange himself cannot be said to have understood his own equations, unaware as he was of the distinction between co-ordinates according as they were *holonomic* or *anholonomic* by analogy with *harmonic* and *anharmonic*."

In the experience of the reviewer Lagrange's equations of motion are not suitable for the treatment of practical problems in engineering, particularly in cases of oscillation about a state of steady motion. The sort of difficulties which arise may be illustrated by a quotation from §99 of the book:—

" It is evident that the equations which determine the vibrations of such a system will in general include *gyroscopic terms* . . . even when the vibrations take place about a position of relative equilibrium. A distinction must accordingly be drawn between vibrations about *equilibrium* and vibrations about *steady motion*, the reason being that vibrations about steady motion are the same as those about equilibrium of the *non-natural* system to which the problem is reduced by the operation known as the *ignoration of co-ordinates*."

In problems connected with the vibration of rotating shafts it is of cardinal importance to start off with a sound physical idea of shaft revolution. In this connection the first person to observe the practical behaviour of a revolving shaft in vibration appears to have been the late Prof. Duffield, of Reading University, who mentioned his observations to the reviewer in the autumn of 1916. And it was during the Irish affair in the early part of that year that Dr. Jeffcott hit upon his theory of shaft revolution at the College of Science, Dublin.

Although the author does not mention Jeffcott, whose theory of shaft revolution was published in *Phil. Mag.* for March, 1919, he dimly outlines this theory on p. 425, but he does not appear to be very definite or clear in its use. Thus, in §109, under the heading " General Theory of Shafts," the author virtually makes the assumption that at a whirling speed a shaft rotates in steady motion about the axis of its bearings in the shape (including amplitude) in which the shaft would hang at rest if supported horizontally. Unfortunately, he fails to point out that he is making this assumption in order to obtain an approximation for the lowest whirling speed by the use of Rayleigh's principle. Further, although he says that his " ultimate aim is that of employing Lagrange's formula," what he really does is to give, subject to his assumptions, two alternative values for potential energy and by equating these he obtains what is an approximation to the lowest whirling speed.

In §§122-3-4 the author deals with the case of the unsymmetrical load of appreciable moments of inertia as, for instance, a two-blade airscrew. The solution of this problem, which is apparently taken from the strength of shafts in vibration* brings out the coupling effect of gyroscopic forces arising from the imposed rotation, which in this particular case results in a range of experimental instability between the two whirling speeds corresponding to the two lateral moments of inertia. The divergence will occur even if the load and shaft are perfectly balanced.

The reviewer was somewhat disappointed to notice that the author did not give a solution of this important and interesting problem by the use of Lagrange's equations of motion.

Facing p. 416 there is a table of deflection coefficients for shafts supported in various ways. The reviewer first became apprised of these results in similar tabular form in R. and M. No. 551 (A.C.A., 1918), and later in the strength of shafts in vibration.

* The strength of shaft in vibration. J. Morris (Crosby Lockwood, 1929; pp. 78-85).

Regarding this table it may be noted that if

$$\gamma_1 = a_{11} W_1, \text{ then } W_1 = (1/a_1)\, \gamma_1 ; \text{ but if}$$
$$\gamma_1 = a_{11} W_1 + a_{12} W_2 + a_{13} W_3 + \ldots ,$$
$$\gamma_2 = a_{12} W_1 + a_{22} W_2 + a_{23} W_3 + \ldots , \text{ etc.},$$

it is *not* correct to infer that reciprocally

$$W_1 = (1/a_{11})\, \gamma_1 + (1/a_{12})\, \gamma_2 + (1/a_{13})\, \gamma_3 + \ldots ,$$
$$W_2 = (1/a_{12})\, \gamma_1 + (1/a_{22})\, \gamma_2 + (1/a_{23})\, \gamma_3 + \ldots , \text{ etc.};$$

and this is what is effectually done on pp. 435-6. Furthermore, the strain energy is *not* given by

$$V = \tfrac{1}{2} \{ (1/a_{11})\, \gamma_1^2 + (2/a_{12})\, \gamma_1 \gamma_2 + (1/a_{22})\, \gamma_2^2 + \ldots \}$$

as appears from p. 415.

On pp. 420-1, where torsional vibration of engine crankshafts is discussed, the author makes use of masses when he means moments of inertia and he calls the frequencies of free vibration critical speeds, which is very confusing.

An interesting feature of the book is the treatment of vibration of structural frames.

In a book of such scope and magnitude it is difficult to avoid errors, but unfortunately this book is marred by faults, some of which are not unimportant.

The book is very replete with diagrams, there being 187 of them.

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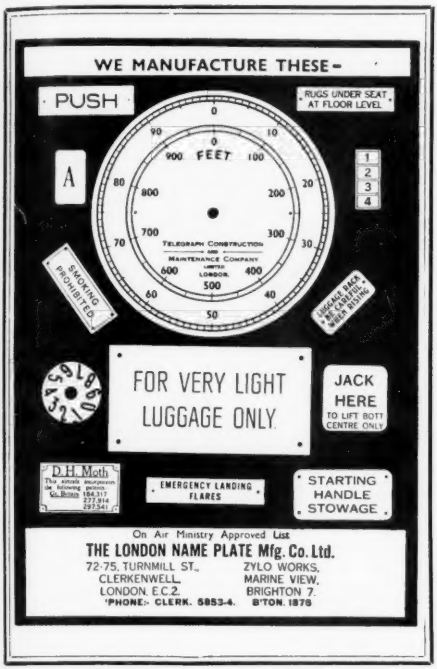

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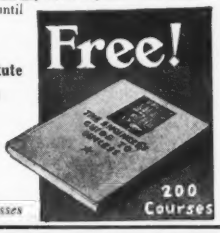

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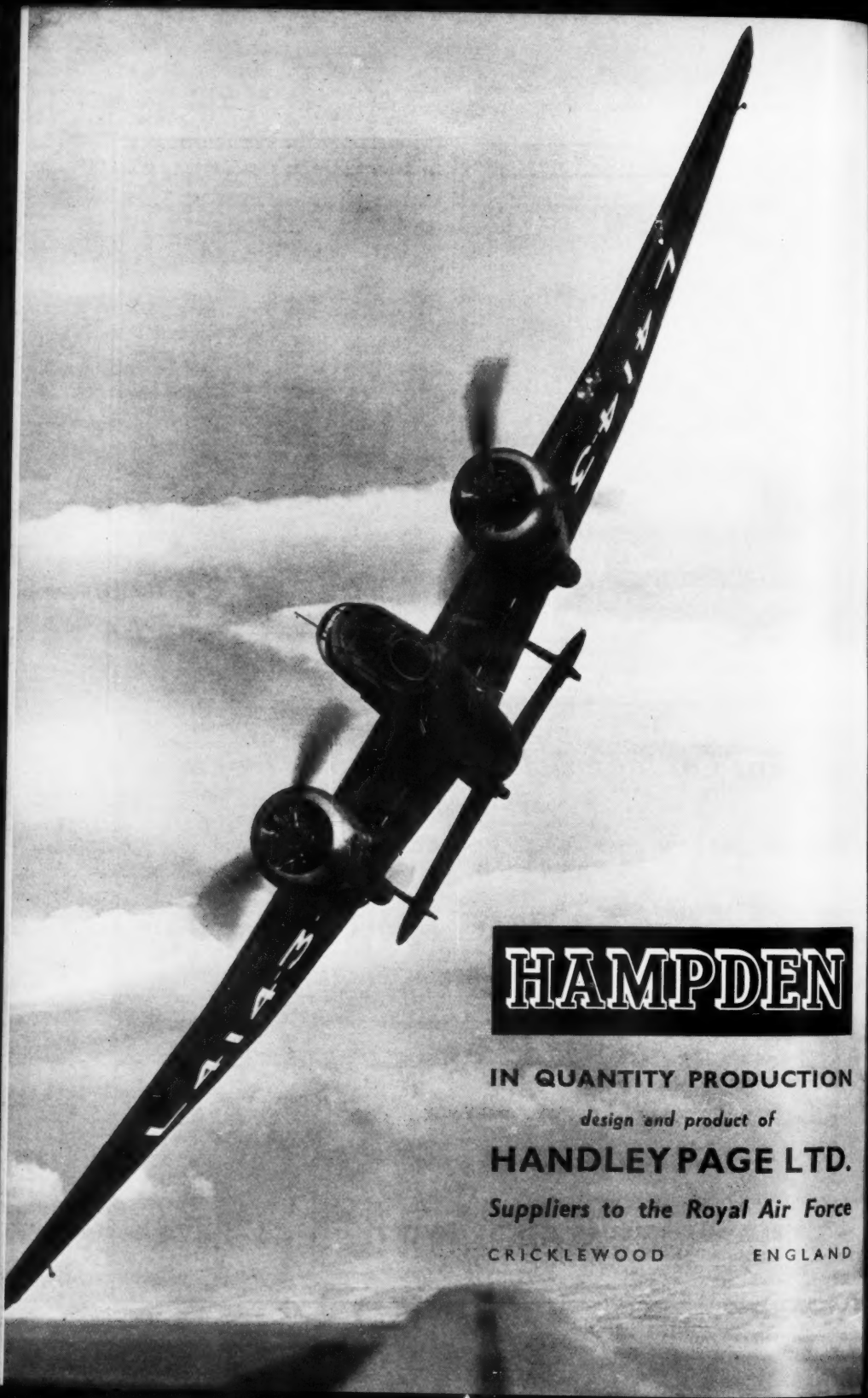
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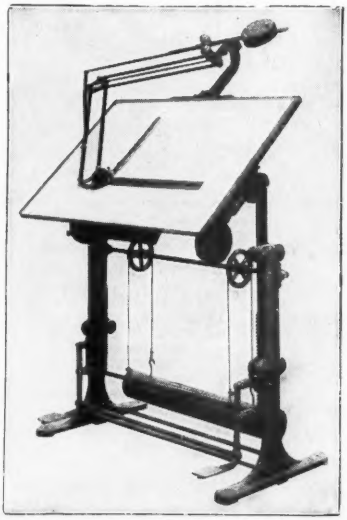

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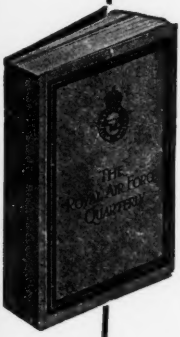

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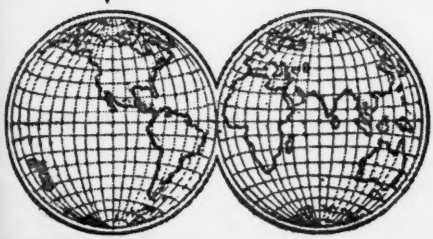

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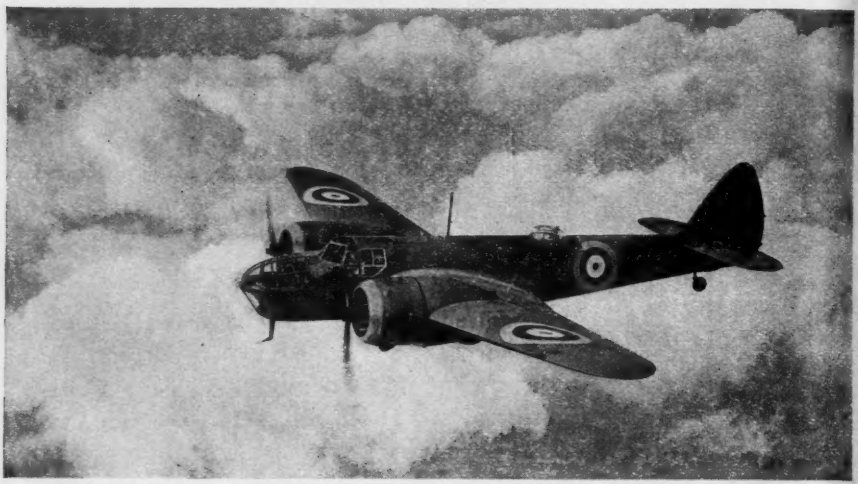

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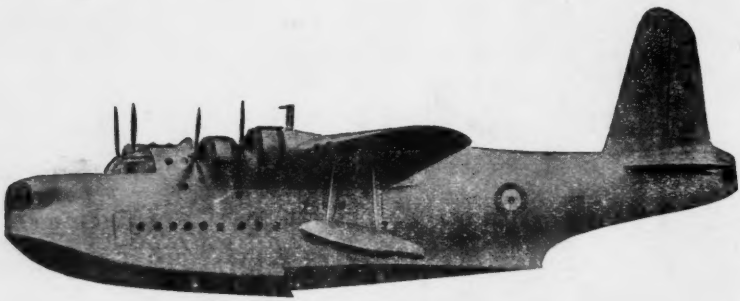

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MONTHLY NOTICES,

APRIL, 1940.

Lecture Visitors.

The attention of all members is specially drawn to the fact that non-members of the Society will not, for the period of the war, be admitted to any of the Society's lectures unless they are in possession of a visitors' ticket, made out to them and *signed by a member of the Society*. This rule will be enforced, following advice from the censorship authorities.

Council Meeting.

A meeting of the Council was held in the offices of the Society on Wednesday, March 20th, 1940.

Present: Mr. A. H. R. Fedden (President) in the chair; Captain P. D. Acland, Lieut.-Col. J. T. C. Moore-Brabazon, Mr. Griffith Brewer (Vice-President), Mr. S. Camm, Mr. W. C. Devereux, Mr. D. L. Ellis, Mr. J. E. Hodgson (Honorary Librarian), Major D. H. Kennedy (Honorary Treasurer), Mr. F. R. Simms (Finance Committee), Mr. A. N. D. Smith (Honorary Accountant), Dr. H. C. Watts, Mr. H. E. Wimperis (Past-President), Mr. R. T. Youngman.

Among the business discussed was the following:—Wilbur Wright Memorial Lecture, 1940; Annual Council Dinner; Education of Aeronautical Engineers; Annual Report of the Council and Income and Expenditure Accounts, 1939; Technical Development of Civil Aviation; Proposed Memorial Prize in memory of the late Mr. R. P. Alston; Lecture Programme; Election of Members; Co-Ordination of Research; Preparation of Abstracts and Memoranda.

Election of Members.

The following members were recently elected:—

Fellows.—James Allen Jamieson Bennett (from Associate Fellow), Percy Pritchard.

Associate Fellows.—Ralph Harrison Archbald, James Leonard Neville Bennett-Baggs, Cecil Louis Cowdrey, Alan Davis, Norman Frederick Downes, George Bertrand Leslie Ellis, James Charles Floyd (from Student), Herbert Edward Hancocke, Arthur William Judge, Francis Hugh Maurice Lloyd, Llywelyn Mawer, William Francis Newell, Alan Ovenden, William Halse Paine, Zdenek Pekarek, Robert Walter Slater, William Henry Stephens (from Student), William Alfred Canning Weetman (from Student), Trevor Cresswell Lawrence Westbrook, Alan Hampden Yates (from Student).

Associates.—Frank Bernard Abbott (from Student), Albert William Fairlie, Allen Harold Claude Greenwood (from Student), Robert Lee Hayes (from Student), Frederick Charles Hentsch (from Student), Richard Sidney Jameson, Andrew John Stephen Morris, Albert Henry Munday, George Frederick Spencer, Sivji Devji Thakker, Geoffrey Embleton Walker.

Graduates.—Arthur St. George Harris (from Student), Harry Maynard, Leslie Alan Nevard, Maurice Sydney Spickernell (from Student).

Students.—Derek Vernon Beadon, Kenneth Douglas Bruce, David A. Campbell, Ernest Ambrose Clifford, Alfred Batson Coggles, Alan Geoffrey Cooper, Ronald Charles Cooper, Alan Crossley, Sydney Thomas Dancer, Christopher Hugh Danielsen, Roy Cyril Day, Victor William Kenneth Day, Alfred Edels, Yehuda Giladi, David Jeffrey Goman, Herbert Maynard Hackett, Ian John Gore Hart, Glen Milton Hobday, Robert John Thurstan Holland, Ralph Lionel Maltby, Cyril Marchant, David Michell, Anthony Wilton Mines, John Kitchen Moakes, Paul Robert Owen, Frank Pawling, Frank Edward Pickles, Eric Lewis Ripley, Cyril Francis Trigg, Leslie Lexborough Tucker, Robert L. Whitelaw, Ralph Darkin Williams, David Arthur Woodley.

Companion.—Kenneth William Chapman (from Student), Robert Dawe, Vernon Alfred Robert French.

Associate Fellowship Examinations.

The next Associate Fellowship Examinations will be held on Wednesday, May 22nd, and Thursday, May 23rd, 1940. Full particulars will be sent direct to candidates who have entered for the examination.

Annual Subscriptions.

Under the Rules, members who have not paid their subscriptions for the current year by April 1st are not entitled to have the JOURNAL sent to them. It is not always possible to send back numbers of the JOURNAL to those who pay their subscriptions some time after April 1st, as many of the JOURNALS go out of print. The restrictions on paper make it necessary to print the minimum number of copies required, and it will not be possible to guarantee supplying back numbers of the JOURNAL in future.

The Council wish to thank all those members who have been prompt in paying their subscriptions. By the members supporting the Society particularly at the present time it is possible to legislate ahead and make arrangements which effect considerable saving against having to work from month to month.

Income Tax.

In response to numerous inquiries with regard to a rebate on Income Tax for their subscriptions, the following is a copy of a letter received from the Principal Inspector of Taxes:—

" Ref. H.R.S. 34/C.I. 4420/63. 18/8/28.

Dear Sir.—Further to your interview with Mr. Stonely at this office on the 19th July, I am now in a position to inform you that the Board of Inland Revenue will not raise objection to the allowance as an expense for Income Tax purposes of annual subscriptions paid by members who are:—

(i) Assessable under Schedule D of the Income Tax Acts in respect of professional or trading profits, subject to the decision of the Commissioners who make the assessment that such subscriptions are sufficiently closely related to the business carried on; or

(ii) Assessable under Schedule E in those cases only in which continual membership of the Society is an essential condition of the terms of appointment.

Yours faithfully,

(Signed) GEO. WILCOCK,

Principal Inspector of Taxes."

Civil Aviation Reports.

The Library has no copies of the first four half-yearly reports on Civil Aviation and the Council would greatly appreciate the gift of any of these reports to complete the set. The reports are: Synopsis of Progress of Work in the Department of Civil Aviation, 1st May, 1919-31st April, 1920 (Cmd. 418); for 1st October, 1919-31st March, 1920 (Cmd. 800); for April 1st, 1920, to September 30th, 1920 (Cmd. 1073).

Acknowledgments.

The Council wish to acknowledge with grateful thanks the gift of extremely interesting books and pamphlets for the Library from Mr. F. R. Simms, Founder Member of the Society, Mr. M. H. Volk, Fellow of the Society, and from Mr. H. R. Trost.

Additions to Library.

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UF. 3.—Ministère de l'Air: Publications Scientifiques et Techniques:—

No. 155. Tourbillons thermoconvectifs dans l'Air, application à la Météorologie. By D. Avsec. Frs. 45.

No. 156. Étude sur l'Utilisation des Anémomètres dans un Courant d'Air Turbulent. By J. Kampé de Fériet, A. Martinot-Lagarde and G. Rollin. Frs. 25.

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No. 88. Étude d'un Appareil de Vieillissement à la Lumiere des Enduits Cellulosiques. By Jean Grard. Frs. 15.

UH. 3.—Atti di Guidonia. (Editoriale Aeronautica, Rome):—

No. 19. Su alcuni Abachi utili nelle Prove al Banco e in Volo dei Motori con Compressore. By Dr. P. L. Torre. Lire 3.

UU.a.—National Advisory Committee for Aeronautics. Technical Notes:—

No. 739. A Recurrence Formula for Shear-Lag Problems. By Paul Kuhn.

No. 740. Stress Concentration around an open Circular Hole in a Plate subjected to Bending Normal to the Plane of the Plate. By C. Dumont.

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No. 742. Pressure-Distribution Measurements on a Rectangular Wing with a Partial-Span Split Flap in Curved Flight. By Frank G. Rokus.

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No. 744. The Development of Electrical Strain Gages. By A. V. de Forest and H. Leadermann.

No. 745. Tests of a Gust-Alleviating Flap in the Gust Tunnel. By P. Donely and C. C. Shufflebarger.

No. 746. The Frequencies of Cantilever Wings in Beam and Torsional Vibrations. By C. P. Burgess.

UU.b.—National Advisory Committee for Aeronautics. Reports:—

No. 665. Calculation of the Aerodynamic Characteristics of Tapered Wings with Partial-Span Flaps. By H. A. Pearson and R. F. Anderson.

No. 669. Airfoil Section Data Obtained in the N.A.C.A. Variable-Density Tunnel as Affected by Support Interference and other Corrections. By E. N. Jacobs and Ira H. Abbott.

No. 673. Experimental Verification of the Theory of Oscillating Airfoils. By Abe Silverstein and Upshur T. Joyner.

No. 674. Cooling on the Front of an Air-Cooled Engine Cylinder in a Conventional Engine Cowling. By M. J. Brevoort and U. T. Joyner.

No. 675. Effects of Elevator Nose Shape, Gap, Balance, and Tabs, on the Aerodynamic Characteristics of a Horizontal Tail Surface. By Harry P. Goett and J. P. Reeder.

No. 678. Interference of Tail Surfaces and Wing and Fuselage, from Tests of 17 Combinations in the N.A.C.A. Variable-Density Tunnel. By Albert Sherman.

UU.b. 25a.—National Advisory Committee for Aeronautics: Twenty-Fifth Annual Report, 1939.

UL. 3.—Institute of Physical and Chemical Research, Tokyo:—
Scientific Papers, Nos. 940-948. Various Authors. December, 1939.

Y. 24.—International Tin Research and Development Council:—
Fourth General Report, 1939.

G.b. 3.—British Standards Institution: Specifications:—

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3L.31. 99 per cent. Aluminium Notched Bars and Ingots for Remelting. 1/-.

2L.40. Aluminium Alloy Bars, Extruded Sections and Forgings (Specific Gravity not more than 2.80). 1/-.

L.44. Soft Aluminium Alloy Extruded Bars and Sections. 1/-.

L.47. Aluminium Coated Aluminium Alloy Sheets and Coils. 1/-.

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No. 21. Strength of Wood Under Repeated Loading. By F. P. Beliankin. 1936.

No. 33. Theory of Strength in Variable Loading. By S. V. Sörensen. 1938.

No. 34. The Influence of Asymmetrical Cycles of Lading and of the Concentration of Stresses on the Strength of Wood under Repeated Loads. By F. P. Beliankin. 1938.

No. 40. Frequency of Proper Vibrations of Rods and Frames and the Dynamic Criteria of their Stability. By V. G. Chudnovsky. 1939.

Forthcoming Events.

April 12th.—Lecture before the Society by Sir Alan Cobham, Hon. F.R.Ae.S., and Mr. Marcus Langley, F.R.Ae.S., on "Flight Refuelling," in the Lecture Hall of the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, W.C.2, at 6.30 p.m. Refreshments will be served before the Meeting.

April 13th.—Lecture before the Graduates and Students Section by Mr. R. Hadekel, B.Sc., A.F.R.Ae.S., on "Undercarriages," in the Offices of the Society, at 4, Hamilton Place, W.1, at 2.30 p.m. Refreshments will be served after the Meeting.

April 19th.—Lecture before the Society by Mr. S. Rogalski, on "Some Aspects of the Aerial Warfare in the German Polish Campaign," in the Lecture Hall of the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, W.C.2, at 6.30 p.m. Refreshments will be served before the Meeting.

April 24th.—Council Meeting in the Offices of the Society at 3 p.m.

COVENTRY BRANCH.

April 2nd.—Lecture before the Coventry Branch by Mr. C. Hall, on "The Production of Steel Bars."

MEDWAY BRANCH.

April 8th.—Lecture before the Medway Branch, by Mr. J. Lankester Parker, A.F.R.Ae.S., on "The Testing of Prototype Aircraft," at 6 p.m.

J. LAURENCE PRITCHARD, *Secretary and Editor.*

STUDY OF AIRSCREWS FOR HIGH SPEED AEROPLANES.

By Lucio Lazzarino.

(Translated by F. M. Buss from "Aerotecnica," July, 1939, by kind permission of Professor Pistolesi.)

Résumé.—It is demonstrated how, with increase in speed, the diameter of optimum efficiency and the maximum possible value of efficiency of an airscrew diminish. The efficiency of a system of two counter-revolving airscrews with different angular velocities is then determined, and the variation of efficiency with variation in the relation between the angular velocities of the two airscrews.

With increase in the height and speed of flight, airscrew performance inevitably falls off, frequently in a marked degree; this being mainly due to the decrease in aerodynamic efficiency of the blade sections at high Mach numbers.[1]

The object of the present article is to analyse the influence exerted upon the performance of an airscrew by the various parameters that determine it, with special reference to those connected with the speed and height of flight.

A similar study has also been made of systems constituted of two counter-rotating airscrews, with a view to comparing them with isolated airscrews designed to absorb the same power under identical conditions.

By the methods here described, an approximate numerical evaluation of the performance can be made, utilising the experimental results which are already to hand.

The efficiency η_r of an airscrew element, taken at the radius r, may be considered as the product of two factors: induced efficiency η_i and wing efficiency η_e.[2]

The induced efficiency η_i may in most cases be considered as practically independent of the position of the airscrew element under consideration: it depends upon the radius R of the airscrew tip, and increases—other things being equal—with increase in R, as will be explained subsequently.

The wing efficiency η_e of an airscrew element depends principally upon the aerodynamic characteristics of its profile; these in their turn are functions of the ratio between the depth and chord of the profile, and also of the Mach number relative to the element under consideration. In the final analysis we find that the value of η_e increases so long as the Mach number remains below a certain critical value. Once this point is passed η_e diminishes more and more rapidly as r increases.

If the Mach number at the blade-tip surpasses the critical value, the efficiency η_R of the terminal element of the airscrew is definitely less than that of other elements nearer the hub: it may even differ markedly from them, given the rapid diminution of η_e with increase in the Mach number of the element of the airscrew blade above the critical value. Hence the efficiency η_R is in this case less than the total efficiency of the airscrew as a whole.

By substituting for the airscrew with radius R another airscrew with a lesser radius R', one can obtain, in spite of the diminution in induced efficiency η_i produced by the reduction in diameter, an increase in the total efficiency η, due to the higher mean value of the wing efficiencies of the airscrew elements.

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[1] A. Betz, in a brief article ("Luftschrauben für grosse Fluggeschwindigkeit," Jahrbuch 1937 der deutschen Luftfahrtforschung) has made a synthesis of the problems of high-speed propulsion, mentioning some of the points that are treated in the present article.

[2] (c.f. Pistolesi: "Aerodinamica," Chapter VI.)

Numerous practical examples have shown the quantitative importance of this fact.

It may, therefore, be interesting to enter more deeply into the considerations mentioned above, since their value, though general in character, assumes particular significance for high-speed aeroplanes. In order to absorb the great power which is an essential of high speeds, these aeroplanes must use airscrews whose peripheral speed is inevitably high. Adding vectorially the aeroplane's own velocity, we obtain exceedingly high relative speeds in the peripheral zone of the airscrew, corresponding to high Mach numbers which sometimes considerably surpass the critical value above which we find the sharp drop in η_e. If, as often happens, the high-speed flight is carried out at altitude, the airscrew performance becomes still worse, since the speed of sound diminishes with increase in height.[3]

Hence, at equal speeds, there is an increase in the Mach numbers of the airscrew blade profiles.

As is well known, the most usual efficiency formula for an airscrew is:—

$$\eta = \{ V_0 \int_{R_1}^{R} dT \} / \{ \Omega \int_{R_1}^{R} dQ \} \quad . \quad . \quad . \quad . \quad (1)$$

where V_0 = speed of flight, Ω = angular velocity of the airscrew, R_1 = radius of the hub, dT, dQ the drag and couple acting on the airscrew element taken at the radius r, *i.e.*,[4]

$$\begin{cases} dT = n\rho\Gamma r \ (\Omega - \omega') \ (1 - \epsilon \tan \phi') \ dr \\ dQ = n\rho\Gamma \ (V_0 + v') \ (1 + \epsilon \cot \phi') \ dr \end{cases} \quad . \quad . \quad . \quad (2)$$

where $\Gamma(r)$ = circulation around the blade profile at radius r, n = number of blades, ρ = density of the air, ω', v' = respectively the increase of angular and axial speed on the airscrew disc, ϵ = inverse of the aerodynamic efficiency of the blade profile, ϕ' = angle between the velocity $r\Omega$ and the effective relative velocity W' of the air with regard to the blade element taken at radius r.

The law of distribution of Γ along the radius may be of any kind: for convenience in calculation, we assume it to be that of the airscrew having minimum loss of energy for induced drag, according to Prandtl's approximate theoretical formula:—

$$\Gamma = \frac{8 \bar{w}'}{n} \frac{V_0 r^2 \Omega^2}{V_0^2 + r^2\Omega^2} \cos^{-1} e^{\frac{-\pi(R-r)}{a}} \quad . \quad . \quad . \quad . \quad (3)$$

where $\bar{w}'$ is a constant and a has the value:—

$$a = \frac{2\pi R V_0}{n \sqrt{(V_0^2 + R^2\Omega^2)}} \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Substituting in (1) the formulæ given in (2), and keeping (3) in mind, we obtain:—

$$\eta = \frac{V_0 \int_{R_1}^{R} \frac{(\Omega - \omega') r^3 \ (1 - \epsilon \tan \phi') \cos^{-1} e^{\frac{-\pi(R-r)}{a}}}{V_0^2 + r^2\Omega^2} dr}{\Omega \int_{R_1}^{R} \frac{(V_0 + v') r^3 \ (1 + \epsilon \cot \phi') \cos^{-1} e^{\frac{-\pi(R-r)}{a}}}{V_0^2 + r^2\Omega^2} dr} \quad . \quad . \quad (5)$$

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[3] c.f. Wenzig: "Luftschrauben für schnelle Flugzeuge" (Jahrbuch 1937 der Deutschen Luftfahrtforschung), who gives the following figures:—

Height m.	0	2000	4000	6000	8000	10,000
Speed of sound, m./sec.	342	335	328	319	310	301

[4] Formulæ (2), (3), (4), (6), (7), (8) can be deduced from Chapter VI of E. Pistolesi's "Aerodinamica."

Remembering the well-known general expressions:—

$$\eta_i = \frac{V_o\,(\Omega-\omega')}{\Omega\,(V_o+v')} = \frac{V_o}{V_o+\bar{w}'} \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

$$\phi_o = \phi' - \alpha_i = \tan^{-1}\frac{V_o}{r\Omega} \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

$$\alpha_i = \frac{v'}{r\,(\Omega-\omega')} = \frac{r\omega'}{V_o+v'} = \frac{\bar{w}'r\Omega}{V_o^2+r^2\Omega^2} \quad . \quad . \quad . \quad . \quad . \quad (8)$$

we may express (5), neglecting the terms which are equal to or less than α_i^2 [5] in the form:—

$$\eta = \eta_i \frac{\int_{R_i}^{R}\left(1+\frac{\bar{w}'r^2\Omega^2}{(V_o^2+r^2\Omega^2)\,V_o}\right)\left(1-\frac{V_o\varepsilon\,(r)}{r\Omega}\right)\frac{r^3\cos^{-1}e^{\frac{-\pi(R-r)}{a}}}{V_o^2+r^2\Omega^2}dr}{\int_{R_i}^{R}\left(1+\frac{\bar{w}'r^2\Omega^2}{(V_o^2+r^2\Omega^2)\,V_o}\right)\left(1+\frac{r\Omega\varepsilon\,(r)}{V_o}\right)\frac{r^3\cos^{-1}e^{\frac{-\pi(R-r)}{a}}}{V_o^2+r^2\Omega^2}dr} \quad . \quad (9)$$

Since, at any given height, ε is essentially a function of $W_o = \sqrt{(V_o^2+r^2\Omega^2)}$, (9) may conveniently be transformed as follows:—

$$\eta = \eta_i \frac{\int_{W_o'}^{W_o''}\left(1+\frac{\bar{w}\,(W_o^2-V_o^2)}{W_o^2V_o}\right)\left(1-\frac{V_o^2\varepsilon\,(W_o)}{\sqrt{(W_o^2-V_o^2)}}\right)\frac{W_o^2-V_o^2}{W_o}\cos^{-1}e^{\frac{n\,W_o''}{2\,V_o}\left(\sqrt{\frac{W_o^2-V_o^2}{W_o''^2-V_o^2}}\right)-1}dW_o}{\int_{W_o'}^{W_o''}\left(1+\frac{\bar{w}'\,(W_o^2-V_o^2)}{W_o^2V_o}\right)\left(1+\frac{\sqrt{(W_o^2-V_o^2)}\,\varepsilon\,(W_o)}{V_o}\right)\frac{W_o^2-V_o^2}{W_o}\cos^{-1}e^{\frac{n\,W_o''}{2\,V_o}\left(\sqrt{\frac{W_o^2-V_o^2}{W_o''^2-V_o^2}}\right)-1}dW_o} \quad (10)$$

In (9) all functions coming under the integral sign, except $\varepsilon\,(r)$ are expressed explicitly as a function of r.

The function $\varepsilon\,(r)$ or $\varepsilon\,(W_o)$ is defined, as mentioned above, not only by the geometrical characteristics of the various blade profiles, but also by the Mach number corresponding to their working conditions. Consequently, $\varepsilon\,(r)$ or $\varepsilon\,(W_o)$ is determined by the height, and by the values of speed of flight and of the angular velocity of the airscrew, as well as by the blade profiles.

The experiments made to determine ε as a function of the Mach number for various profiles are still few in number, and the results show considerable discrepancies. These are due in the main to the different conditions in which the experiments were carried out, which in turn are quite other than those which are obtained on airscrew blades.[6] In tests of this kind, experimental errors due to the system employed are of importance: it is difficult to estimate them exactly, owing to the delicacy and complexity of the measurements.

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[5] If it is desired to take into account the terms α_i^2 and $\varepsilon\,\alpha_i$, omitted above, formula (5) becomes:—

$$\eta = \eta_i \frac{\int_{R_i}^{R}\left(\sin^2\phi_o+\frac{\alpha_i\cos\phi_o\sin\phi_o-\alpha_i^2\sin^2\phi_o}{1+\alpha_i^2}\right)r^3\left(1-\varepsilon\frac{\sin\phi_o+\alpha_i\cos\phi_o}{\cos\phi_o-\alpha_i\sin\phi_o}\right)\cos^{-1}e^{-\pi(R-r)/a}dr}{\int_{R_i}^{R}\left(\sin^2\phi_o+\frac{\alpha_i\cos\phi_o\sin\phi_o-\alpha_i^2\sin^2\phi_o}{1+\alpha_i^2}\right)r^3\left(1+\varepsilon\frac{\cos\phi_o-\alpha_i\sin\phi_o}{\sin\phi_o+\alpha_i\cos\phi_o}\right)\cos^{-1}e^{-\pi(R-r)/a}dr} \quad (11)$$

[6] c.f. I. Stack and A. E. von Doenhoff; Tests of 16 Related Airfoils at high speeds. N.A.C.A. Report No. 492, 1934; A. Ferri: Studi e ricerche eseguite alla Galleria Ultrasonora di Guidonia. Hauptversammlung 1938 der Lilienthal Gesellschaft. (Translated, R.Ae.S. Journal, October, 1939.)

Having determined the Mach numbers of the blade profiles, as a function of r and of the height and speed of flight, taking into account where necessary the results of previous experiments, one can construct an approximate representation of the function $\epsilon(r)$, from which the integrals of formula (9) may be deduced either by a graph or by calculation.

Obviously the degree of accuracy of results obtained by these means depends upon the accuracy with which the function $\epsilon(r)$ or $\epsilon(V_0)$ can be determined. It may be remarked, however, that on account of the rapid increase of ϵ above the critical value of Mach number, the range of r comprised between the value corresponding to the critical value and the value of R corresponding to optimum airscrew efficiency is usually limited; hence even a noticeable error in evaluating the said range will lead to a much smaller relative error in determining the radius of optimum airscrew performance—at least in the cases which are most frequent in practice.

When calculating η by means of formula (9), η_i must be determined by (6); hence also the constant $\bar{w}'$ contained therein. This last parameter can be calculated with a good approximation, starting with the formula of the power II absorbed by the airscrew:—

$$\Pi = \Omega n \int_{R_i}^{R} \rho \Gamma' (V_0 + v') \, r dr \quad . \quad . \quad . \quad . \quad . \quad (12)$$

Introducing into (12) the value of Γ' given by formula (3), and keeping in mind the final term of (8), we arrive (neglecting the terms in a_i^2) at the second degree equation in $\bar{w}'$:—

$$\Pi = \bar{w}' \, 8 \, \rho \Omega^2 V_0^2 \int_{R_i}^{R} \frac{r^3 \cos^{-1} e^{\frac{-\pi(R-r)}{a}}}{V_0^2 + r^2\Omega^2} dr + \bar{w}'^2 \, 8 \, \rho V_0 \Omega^4 \int_{R_i}^{R} \frac{r^5 \cos^{-1} e^{\frac{-\pi(R-r)}{a}}}{(V_0^2 + r^2\Omega^2)^2} dr \quad (13)$$

from which an approximate value for $\bar{w}'$ may be obtained. Given the power II absorbed by the airscrew, the speed V_0 and the height of flight, it is possible by means of formula (9) to construct the function $\eta(R)$, finding out its maximum value and the corresponding optimum diameter.

In applying the procedure described, it must be remembered that the formulæ used are valid for incompressible fluids; therefore in function $\epsilon(r)$ or $\epsilon(V_0)$ must be included all corrections due to the compressibility of the fluid. If at any point a relative velocity between the airscrew and the air is reached which surpasses the speed of sound, the formulæ adopted have merely an indicative and so to speak conventional value, because there is a noticeable change in the aerodynamic phenomena which occur around those portions of the airscrew which are moving at supersonic speed.[7]

The distribution of circulation along the blade which is defined in (3) has been adopted because it allows the induced efficiency η_i to be separated from the mean wing efficiency of the airscrew, expressed by the fraction figuring in (9); this renders the process clearer.

It would, however, be possible to assume any desired distribution of Γ' and apply the method, using only the formulæ (1), (2) and (8), which are valid in all cases.

The following example illustrates the application of the method, and may give a useful indication of the size of the quantities involved:—

* * *

Let us assume that the airscrew absorbs 1,400 h.p. = 105,000 kgm./sec.: it is working at a speed of 200 m./sec.; the height is 6,000 metres; r.p.m. 1,910, corresponding to $\Omega = 200$ sec.$^{-1}$; the number of blades is three.

[7] c.f. A. Buseman: Sostentazione aerodinamica a velocità superiore a quella del suono. Aerotecnica, August-September, 1936.

Having obtained the function $a = a(R)$ by means of formula (4), working out (13) for various values of R, we obtain the function $\bar{w}' = \bar{w}'(R)$; hence, by means of (6), the function $\eta_i = \eta_i(R)$ obtaining the following result (see also Fig. 1):—

R m.	a	w' m./sec.	η_i
0.8	1.308	71.08	0.738
0.9	1.401	46.44	0.812
1.0	1.481	31.87	0.863
1.1	1.550	22.89	0.897
1.2	1.609	16.97	0.922
1.3	1.660	12.95	0.939
1.4	1.704	10.13	0.952
1.5	1.743	8.08	0.961
1.6	1.776	6.56	0.968

Utilising the experimental data that can be deduced from the two books quoted above, we then assume the following approximate values of the function $\epsilon(r)$:—

r = (m.)	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4
ϵ =	0.0556	0.0581	0.0614	0.0667	0.0730	0.0826	0.0990	0.1163	0.1351	0.1515	0.1695	0.1786	0.1818

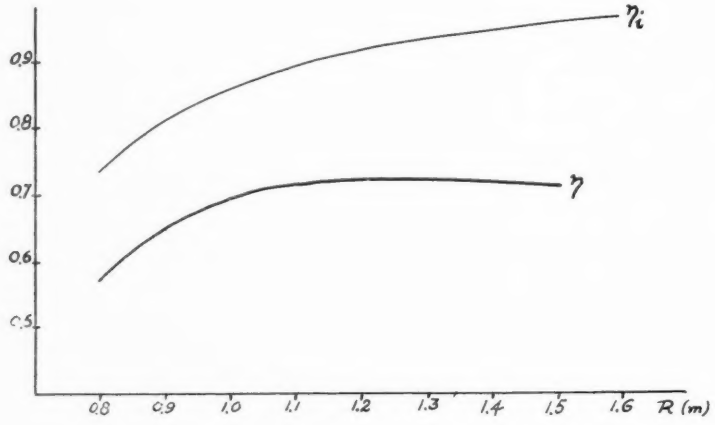

FIG. 1.

Finally, working out (9), we find (again refer to Fig. 1):—

R (m.) ...	1.0	1.1	1.2	1.3	1.4
η	0.693	0.714	0.725	0.727	0.725

These calculations would lead one to conclude that the optimum diameter of the airscrew is about 2.60 m., and the maximum possible efficiency only 0.727.

The practical value of the results depends upon the reliability of the form adopted for the function $\epsilon(r)$, which in the present experimental stage of our research must be accepted with some reserve. In any case, the example quoted shows how, in conditions of high-speed flight, when an airscrew has to absorb considerable power at high r.p.m., the efficiency is likely to be much lower than that which is found at slow speeds. It is perhaps interesting to quote the values of $\eta\epsilon$ for various values of r, referring to the more efficient airscrew (see also Fig. 2).

r = (m.).	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2
$\eta\epsilon$ ...	0.780	0.817	0.832	0.836	0.829	0.808	0.787	0.760	0.738	0.713

From the above table we see that profile efficiency is rather low in the periphery of the airscrew; to this is due the low efficiency of the airscrew as a whole, for the induced efficiency is fairly high.

In the example quoted, we took the distribution of lift along the airscrew blades given by formula (3). This was in order that we could easily obtain a separate value of the induced efficiency of the airscrew as a whole; this enabling us to show more clearly the quantitative behaviour of the functions of r that determine the airscrew performance. From an examination of the $\eta_\epsilon(r)$ table, or from Fig. 2, it may be deduced that the distribution of circulation Γ along the airscrew blade adopted is not the best one, although it gives minimum induced drag. With a slightly different distribution, *i.e.*, one that would locate the greater part of the total airscrew thrust in regions of the blade placed at a certain distance from the tips, one could perhaps obtain better total efficiency, despite the increase in induced drag.

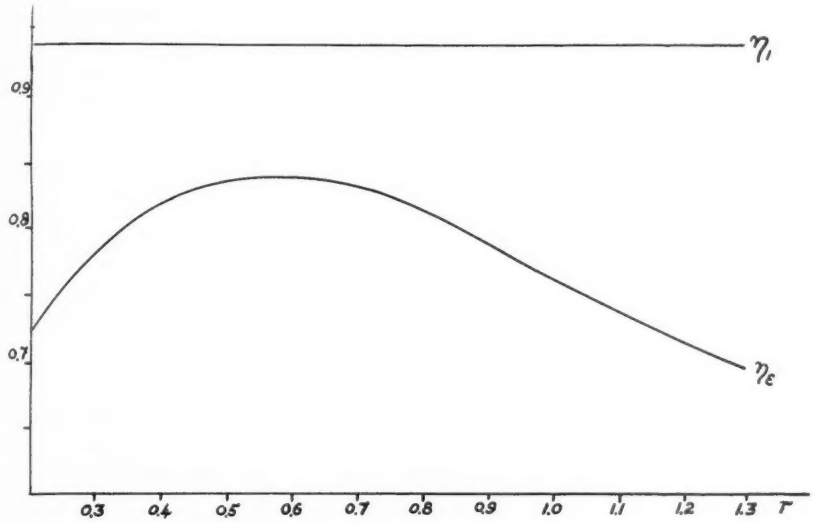

FIG. 2.

The nature of the function $\epsilon(r)$—bound up, in some way which the experimental data is still too scanty to define, with the relationship between the speeds V_0 and Ω and the speed of sound, and also with the constructional geometric characteristics of the blades—makes it difficult to solve the problem of finding the real optimum distribution of circulation Γ along the blade.

In practice this could be effected by a long series of experiments, conducted analytically by means of a systematic application of formulæ (1), (2) and (8), or, better still, by actual test, using criteria similar to those mentioned above.

* * *

We have seen how the low efficiency of airscrews in high-speed aeroplanes depends essentially upon the high values of relative velocity $\sqrt{(V_0^2 + r^2\Omega^2)}$ found over a great portion of the airscrew. To diminish this, Ω must be reduced to the lowest value consistent with the requirements of the engine and the reduction gear. Reasons of weight and constructional idiosyncrasies here impose limits which it is difficult to overstep. The diameter of the airscrew cannot be reduced below a certain point, because of increase in induced drag. There remains, therefore, only the possibility of diminishing the power absorbed by each air-

screw, by dividing up the total power of the aeroplane among a suitable number of airscrews, so that the diameter of each airscrew can be reduced without too much increase in induced drag. This is equivalent to sub-dividing the total power among a large number of airscrews having a smaller optimum diameter and a greater efficiency.

The simplest and best way of doing this is to increase the number of airscrews, which, in the present state of our technique, means a larger number of engines. Reasons of weight, constructional simplicity, and the lines of the aeroplane—which is designed with a view to the purpose for which it is intended—are usually the factors determining the number of engines. It may, therefore, sometimes be advisable to adopt the arrangement of co-axial counter-revolving airscrews governed by the same engine, whenever it is not possible to divide the power among separate airscrews; this has already been done in some cases.[8]

Hence, the problem is to study what conditions this arrangement should fulfil, in order to give maximum efficiency.

Let us consider a system of two co-axial airscrews of equal diameter, rotating with angular velocities opposite in direction.

All quantities referring to the first airscrew will be designated 1, and all those referring to the second will be designated 2. Any quantity with no distinguishing figure is to be taken as referring to the system as a whole. Let the two co-axial counter-revolving airscrews be placed very close together, so that their middle plane may be regarded as coincident. It is assumed that the two airscrews are constructed in such a way as to give opposite induced increases ω' of angular velocity to the wake, thus cancelling the greater part of the total reactive couple of the system. The structural and aerodynamic advantages of this are obvious. Thus we have:—

$$\omega_1' = -\omega_2' = \omega' \qquad . \quad . \quad . \quad . \quad . \quad (14)$$

Applying formula (8) to each of the counter-revolving airscrews and adding up the expressions thus obtained, we find the value v' of increase in axial velocity, in the common middle plane, given by the two counter-rotating airscrews:—

$$v' = v_1' + v_2' = \frac{r^2\omega'(\Omega_1 - \Omega_2)}{V_0 + v'} \qquad . \quad . \quad . \quad . \quad (15)$$

The induced efficiency of the system constituted by the two elementary counter-rotating sections of the two airscrews, taken at the generic radius r, is:—

$$\eta_{ir} = \frac{1}{1 + v'/V_0} \qquad . \quad . \quad . \quad . \quad . \quad (16)$$

The nature of the propulsive system under consideration makes it probable that the series of spiral vortices starting from the blades of the first airscrew are perturbed and, in a certain way, broken up by the action of the blades of the second airscrew. The phenomena which develop to leeward of the two airscrews are certainly very complicated and of a periodic nature, but within a relatively short portion of the wake, the increase in angular velocity (nil in the middle plane) will trend rapidly towards zero, being damped out in each particle by the influence of the surrounding particles. At the same time, the increase in axial velocity will tend to have a mean value in all sections of the wake, except in the peripheral zone.

For our present purpose it is sufficiently accurate to consider the system under examination as being one which does not give any increase in angular velocity in the wake, but does give a constant increase v' in axial velocity over the whole disk covered by the two airscrews.

The induced efficiency will everywhere be equal to its mean value:—

$$\eta_i = \frac{1}{(1 + v'/V_0)} \qquad . \quad . \quad . \quad . \quad . \quad . \quad (17)$$

[8] c.f. M. Castoldi: "Gli Apparecchi Italiani di alta Velocità"; Conference of Physical, Mathematical and Natural Sciences, 1935. R. Accademia d'Italia.

where v' must satisfy the condition of assuring the system a given traction T. From the term :—

$$T = 2\,\pi\rho \int_{R_1}^{R} (v_0 + v')\, v'\, dr \qquad (18)$$

which expresses the theorem of the quantities of motion applied to the whole propulsive system, we find :—

$$v' = -\frac{V_0}{2} + \sqrt{\frac{V_0^2}{4} + \frac{T}{\pi\rho\,(R^2 - R_1^2)}} \qquad (19)$$

or, dividing both sides by V_0 :—

$$\frac{v'}{V_0} = -\tfrac{1}{2} + \sqrt{\tfrac{1}{4} + \frac{T}{\pi\rho\,(R^2 - R_1^2)\,V_0^2}} \qquad (20)$$

The double of the second half of the square root term is commonly known as *load coefficient*.

From (18) we derive further :—

$$[V_0 + v']\, v' = \frac{T}{\pi\rho\,(R^2 - R_1^2)} \qquad (21)$$

which, introduced into (15) gives us the following expression of ω' :—

$$\omega' = \frac{T}{\pi\rho\,(R^2 - R_1^2)\,(\Omega_1 - \Omega_2)}\,\frac{1}{r^2} = \frac{C}{r^2} \qquad (22)$$

where C is obviously a quantity independent of r, being a function of T, R, R_1 and $(\Omega_1 - \Omega_2)$.

Applying formula (2) to each of the counter-rotating airscrews and introducing into (1) the terms thus obtained, dT_1, dT_2, dQ_1, dQ_2, we have in this case :—

$$\eta = \frac{V_0 \int_{R_1}^{R} [n_1\Gamma_1\,(\Omega_1 - \omega')\,(1 - \epsilon_1 \tan\phi_1') + n_2\Gamma_2\,(\Omega_2 - \omega')\,(1 - \epsilon_2 \tan\phi_2')]\, rdr}{\left[\Omega_1 \int_{R_1}^{R} n_1\Gamma_1\,(1 + \epsilon_1 \cot\phi_1')\, rdr + \Omega_2 \int_{R_1}^{R} n_2\Gamma_2\,(1 + \epsilon_2 \cot\phi_2')\, rdr\right](V_0 + v')} \qquad (23)$$

From (23) it is clear that η is proportional to the induced efficiency η_i and to a quantity which depends firstly upon the aerodynamic characteristics of the blade profiles of the two airscrews—characteristics corresponding to the Mach numbers at which the profiles function—and secondly upon the ratio $x = \Omega_2/\Omega_1$.

To clarify this last factor, we now put temporarily for each value of r :—

$$\epsilon_1 \simeq \epsilon_2 \simeq \epsilon \qquad (24)$$

Comparing (8) with the known general term :—

$$a_i = \frac{1}{4\,\pi r}\,\frac{n\Gamma}{W' \sin\phi'} \qquad (25)$$

we obtain, bearing in mind (22) :—

$$n_1\Gamma_1 = -n_2\Gamma_2 = 4\,\pi C \qquad (26)$$

Then, using the formula :—

$$\left|\tan\phi'\right| = \left|\frac{V_0 + v'}{r\,(\Omega - \omega')}\right| \qquad (27)$$

which must be applied only as an absolute value, and also (21), (24) and (26), we can write (23) in the form :—

$$\eta = \frac{V_0\,[(\Omega_1 - \Omega_2)\,(R^2 - R_1^2) - 4\,(V_0 + v')\int_{R_1}^{R} \epsilon dr]}{(V_0 + v')\,(\Omega_1 - \Omega_2)\,(R^2 - R_1^2) + 2\,(\Omega_1^2 + \Omega_2^2)\int_{R_1}^{R} \epsilon r^2 dr - 2\,v'\,(V_0 + v')\int_{R_1}^{R} \epsilon dr} \qquad (28)$$

Putting for short :—

$$\frac{2}{R^2-R_1^2}\int_{R_1}^{R}\epsilon dr=A \quad . \quad . \quad . \quad . \quad . \quad . \quad (29)$$

$$\frac{2}{R^2-R_1^2}\int_{R_1}^{R}r^2\epsilon dr=B \quad . \quad . \quad . \quad . \quad . \quad . \quad (30)$$

introducing the parameter $x=\Omega_1/\Omega_2$ and dividing the numerator and denominator of fraction (28) by $\Omega_1 V_0 (R^2-R_1^2)$, we obtain :—

$$\eta=\frac{1-x-2\dfrac{V_0+v'}{\Omega_1}A}{\dfrac{1-x}{\eta_1}+\dfrac{\Omega_1(1+x^2)}{V_0}B-\dfrac{v'}{\eta_1\Omega_1}A} \quad . \quad . \quad . \quad . \quad (31)$$

Integrating (31) with regard to x and equating to zero, we obtain a second grade equation in x from which the optimum value of x can be deduced :—

$$x_{opt}=1-2\frac{V_0+v'}{\Omega_1}\left[1-\sqrt{\left(1-2\frac{V_0+v'}{\Omega_1}A\right)^2+1+\frac{2V_0^2A}{\eta_1\Omega_1^2B}}\right] \quad . \quad . \quad (32)$$

The value x_{opt} in (32) is essentially determined by V_0/Ω_1 because v' is usually small by comparison with V_0 and with the quantities A and B which depend upon the aerodynamic characteristics of the blade profiles, and consequently upon the Mach number which corresponds to the operating conditions of these blades.

Formula (32) is based upon the hypothesis expressed in (24). The value of x_{opt} must therefore be considered merely approximate, unless the result of (32) is $x_{opt}=-1$. The value of x_{opt} given by (32) will be sufficiently accurate if it is near to -1. If x_{opt} is too far from this value, (24) cannot be considered valid, and x_{opt} will then have to be determined by a second approximation.

Having, in fact, obtained from (32) a first approximation of the angular velocity $\Omega_2=x'_{opt}\Omega_1$ of the second airscrew, the ϵ_2 of its various profiles, corresponding to the Mach number relating to their operating conditions, can now be determined.

As (24) no longer holds good, (23) instead of leading to (28) gives rise to :—

$$\eta=\frac{V_0\left[(\Omega_1-\Omega_2)(R^2-R_1^2)-2(V_0+v')\left(\int_{R_1}^{R}\epsilon_1dr+\int_{R_1}^{R}\epsilon_2dr\right)\right]}{(V_0+x')(\Omega_1-\Omega_2)(R^2-R_1^2)+2\Omega_1^2\int_{R_1}^{R}\epsilon_1r^2dr+2\Omega_2^2\int_{R_1}^{R}\epsilon_2r^2dr-2C\Omega_1\int_{R_1}^{R}\epsilon_1dr-2C\Omega_2\int_{R_1}^{R}\epsilon_2dr} \quad (28')$$

where the value of C is a first approximation obtainable from (22).[9]

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[9] One could, on the other hand, take the value of C given by (22), leaving the factor $(\Omega_1-\Omega_2)$, which appears in the denominator, as an unknown. For (31') must be substituted :—

$$\eta=\frac{1-x-\dfrac{V_0+v'}{\Omega_1}(A_1+A_2)}{\dfrac{1-x}{\eta_1}+\dfrac{\Omega_1B_1}{V_0}+\dfrac{\Omega_1B_2}{V_0}x^2-\dfrac{T}{\pi\rho(R^2-R_1^2)\Omega_1(1-x)V_0}}$$

which, integrated with regard to x and equated to zero, gives rise to a fourth degree algebraic equation, whose solution still does not give the exact value of x_{opt}, because A_1, A_2, B_1, B_2 are approximate.

Writing now for short :—

$$\left.\begin{aligned} A_1 &= \frac{2}{R^2 - R_1^2}\int_{R_1}^{R} \epsilon_1 dr \\ A_2 &= \frac{2}{R^2 - R_1^2}\int_{R_1}^{R} \epsilon_2 dr \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad (29')$$

$$\left.\begin{aligned} B_1 &= \frac{2}{R^2 - R_1^2}\int_{R_1}^{R} \epsilon_1 r^2 dr \\ B_2 &= \frac{2}{R^2 - R_1^2}\int_{R_1}^{R} \epsilon_2 r^2 dr \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad (30')$$

we obtain from (28'), in the same way as we obtained (31) from (28) :—

$$\eta = \frac{1 - x - \frac{V_0 + v'}{\Omega_1}(A_1 + A_2)}{\frac{1 - x}{\eta_0} + \frac{\Omega_1 B_1}{V_0} + \frac{\Omega_1 B_2}{V_0}x^2 - \frac{C}{V_0}(A_1 - A_2 x)} \quad . \quad . \quad . \quad . \quad (31')$$

from which, integrating with regard to x and equating to zero, we obtain a second approximation of x_{opt}, *i.e.* :—

$$x_{opt} = 1 - \frac{V_0 + v'}{\Omega_1}(A_1 + A_2) - \quad (32')$$

$$- \sqrt{\left[1 - \frac{V_0 + v'}{\Omega_1}(A_1 + A_2)\right]^2 + \frac{B_1}{B_2} - \frac{C(A_1 - A_2)}{\Omega_1 B_2} + \frac{V_0 (V_0 + v')(A_1 - A_2)}{\Omega_1^2 B_2}\left(\frac{1}{\eta_0} - \frac{CA_2}{V_0}\right)}$$

In the same way one could obtain a third approximation, and so on.

Obviously formulæ (32) and (32') are useful in cases where Ω_1 is fixed and Ω_2 must be determined, all the other independent parameters remaining fixed; the results deducible from them are of practical use when the absolute value of Ω_2 thus obtained does not too greatly surpass Ω_1; if it does, constructional reasons will prevent the realisation of the velocity Ω_2. It will then be necessary to examine the possibility of reducing Ω_1. In this case formulæ (32) and (32') no longer hold good. From (31) and (31'), which are still valid, we can obtain directly values of η as a function of Ω_1 and Ω_2, and find by experiment the most suitable solution.

It is quicker to find x_{opt} by using, instead of Ω_1 or Ω_2 a parameter which links together Ω_1 and Ω_2, so that when one has been fixed the other is also determined, and which expresses a condition imposed by the engine or by the reduction gear.

If, for example, we state that the mean value Ω^* of the absolute values of angular velocity Ω_1 and Ω_2 shall remain invariable; *i.e.*, if we write :—

$$\left.\begin{aligned} \Omega_1 &= 2\,\xi\Omega^* \\ -\Omega_2 &= 2\,(1 - \xi)\,\Omega^* \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad (33)$$

formula (31') can be replaced by the simpler term :—

$$\eta = \frac{V_0\left[2\,\Omega^* - (V_0 + v')(A_1 + A_2)\right]}{2\,(V_0 + v')\,\Omega^* + 4\,B_1\xi^2\Omega^{*2} + 4B_2\,(1 - \xi)^2\Omega^{*2} - 2\,A_1 C\xi\Omega^* - 2\,A_2 C\,(1 - \xi)\,\Omega^*} \quad (34)$$

where C has the value given by (22), which here is independent of ξ.

The optimum value of ξ must be found by experiment, because it is impossible to express exactly by means of analysis the quantities A_1, A_2, B_1, B_2, as functions of ξ, C, V_0, Ω^*, T, R, R_1.

It may be useful to consider the case in which the values of ϵ and hence of A, B, may be considered independent of ξ. Expressing (34) in the form :—

$$\eta = \eta_i \frac{1 - \frac{A}{\Omega^* \eta_i}}{1 + \frac{2\eta_i B \Omega^*}{V_0}(2\xi^2 - 2\xi + 1) - \frac{AC\eta_i}{V_0}(2\xi - 1)} \quad . \quad . \quad (34')$$

integrating with regard to ξ, assuming A and B to be constant, and equating to zero, we obtain the optimum value of ξ :—

$$\xi_{opt} = \tfrac{1}{2} + \frac{AC}{4B\Omega^*} \quad . \quad . \quad . \quad . \quad . \quad . \quad (35)$$

This formula serves as a guide for the experimental research mentioned above. It may be considered as a good approximation in cases where the counter-revolving airscrews have comparatively low Mach numbers.

If it were possible to express analytically the functions $\epsilon_1(r)$, $\epsilon_2(r)$, the optimum value of x or ξ could be made by way of analysis. Let us assume, for example, that $\epsilon(r)$ has the constant value ϵ_0 up to a certain value M_1 of Mach number, above which ϵ grows in proportion to the difference $M - M_1$ between the generic Mach number M and M_1. In other words, we write :—

$$\left.\begin{array}{ll} \text{for } \dfrac{\sqrt{(V_0^2 + r^2\Omega^2)}}{u} < M_1 & \epsilon = \epsilon_0 \\ \text{for } M_1 \leq \dfrac{\sqrt{(V_0^2 + r^2\Omega^2)}}{u} & \epsilon = \epsilon_0 + a\left(\dfrac{\sqrt{(V_0^2 + r^2\Omega^2)}}{u} - M_1\right) \end{array}\right| \quad . \quad (36)$$

where u is the speed of sound. This is obviously the simplest hypothesis which can be made concerning the nature of the function ϵ, and it can be considered—as is often done in similar problems—a first approximation.

ϵ will then be constant up to the radius :—

$$R' = \frac{\sqrt{(u^2 M_1^2 - V_0^2)}}{\Omega} \quad . \quad . \quad . \quad . \quad . \quad (37)$$

above which it will vary in accordance with the law expressed in the second term of (36).

For (29), (30) and (29′), (30′) will then be substituted the terms :—

$$A = \frac{2}{R^2 - R_1^2}\left\{\int_{R_1}^{R'} \epsilon_0 dr + \int_{R'}^{R}\left[\epsilon_0 + \frac{a}{u}(\sqrt{[V_0^2 + r^2\Omega^2]} - uM_1)\right]dr\right\} \quad . \quad (29'')$$

$$B = \frac{2}{R^2 - R_1^2}\left\{\int_{R_1}^{R'} \epsilon_0 r^2 dr + \int_{R'}^{R}\left[\epsilon_0 + \frac{a}{u}(\sqrt{[V_0^2 + r^2\Omega^2]} - uM_1)\right]r^2 dr\right\} \quad . \quad (30'')$$

which when integrated give :—

$$\left.\begin{array}{l} A = A' + \dfrac{A''}{\Omega} \\ B = B' + \dfrac{B''}{\Omega^2} \end{array}\right| \quad . \quad . \quad . \quad . \quad . \quad . \quad (38)$$

where A', A'', B', B'' have the respective values :—

$$\left.\begin{array}{l} A' = \dfrac{2}{R^2 - R_1^2}\left[\epsilon_0(R - R_1) - auM_1(R - R'_1)\right] \\ B' = \dfrac{2}{R^2 - R_1^2}\left[\epsilon_0 \dfrac{R^3 - R_1^3}{3} - auM_1 \dfrac{R^3 - R'^3}{3}\right] \end{array}\right| \quad . \quad . \quad (39)$$

$$A'' = \frac{2u}{R^2 - R_1^2}\left\{\frac{a}{2}\left[M(R)\sqrt{(M^2(R) - M_A^2)} - M_1\sqrt{(M_1^2 - M_A^2)} + M_A^2 \log\frac{\sqrt{\{M^2(R) - M_A^2 + M(R)\}}}{\sqrt{(M_1^2 - M_A^2)} + M_1}\right]\right\}$$

$$B'' = \frac{2a}{R^2 - R_1^2}\left\{\frac{u^3}{4}\left[\left(M^3(R) - \frac{M_A^2 M(R)}{2}\right)\sqrt{(M^2(R) - M_A^2)} - \left(M_1^3 - \frac{M_A^2 M_1}{2}\right)\sqrt{(M_1^2 - M_A^2)}\right] + \frac{V_0^3 M_A}{8}\log\frac{\sqrt{\{M^2(R) - M_A^2 + M(R)\}}}{\sqrt{(M_1^2 - M_A^2)} + M_1}\right\} \quad (39')$$

in which $M(R)$ is the Mach number relating to the tip of the blade, and is $M_A = V_0/u$. Formulæ (31′) and (34) become:—

$$\eta = \frac{1 - x - \frac{V_0 + v'}{\Omega_1}\left(2A' + \frac{A''}{\Omega'}\,\frac{x-1}{x}\right)}{\frac{1-x}{\eta_i} + \frac{\Omega_1 B'}{V_0}(1 + x^2) + \frac{B''}{V_0\Omega_1^2}\,\frac{x-1}{x} - \frac{C}{V_0}\left[A'(1-x) + \frac{2A''}{\Omega_1}\right]}. \quad (31'')$$

$$\eta = \frac{V_0\left[2\Omega^* - (V_0 + v')\left(2A' + \frac{A''}{2\Omega^*(\xi - \xi^2)}\right)\right]}{2(V_0 + v')\Omega^* + 8B'\Omega^{*2}(\xi^2 - \xi + \frac{1}{2}) + \frac{B''}{2\Omega^*(\xi - \xi^2)} - 2C(\Omega^* A' + A'')} \quad (34'')$$

These when integrated, the first with reference to x and the second to ξ, and equated to zero, give rise to the two following algebraic equations in x or in ξ, from which the optimum values of x or ξ may be obtained:—

$$\left(1 + \frac{V_0 + v'}{\Omega_1^2}A''\frac{1}{x^2}\right)\left[\frac{1-x}{\eta_i} + \frac{\Omega_1 B'}{V_0}(1 + x^2) + \frac{B''}{V_0\Omega_1^2}\,\frac{x-1}{x} - \frac{C}{V_0}\left(A'(1-x) + \frac{2A''}{\Omega_1}\right)\right] + \left[\frac{2\Omega_1 B'}{V_0}x - \frac{1}{\eta_i} + \frac{CA'}{V_0} + \frac{B''}{V_0\Omega_1^2}\,\frac{1}{x^2}\right]\left[1 - x - \frac{V_0 + v'}{\Omega_1}\left(2A' + \frac{A''}{\Omega_1}\,\frac{x-1}{x}\right)\right] = 0 \quad (40)$$

$$\frac{A''}{2\Omega^*}\,\frac{2\xi - 1}{\xi^4 - 2\xi^3 + \xi^2}\left[2(V_0 + v')\Omega^* + 8B'\Omega^{*2}(\xi^2 - \xi + \tfrac{1}{2}) + \frac{B''}{2\Omega^*(\xi - \xi^2)} - 2C(\Omega^* A' + A'')\right] + \left[2\Omega^* - (V_0 + v')\left(2A' + \frac{A''}{2\Omega^*(\xi - \xi^2)}\right)\right]\left[8B'\Omega^{*2}(2\xi - 1) + \frac{B''}{2\Omega^*}\,\frac{2\xi - 1}{\xi^4 - 2\xi^3 + \xi^2}\right] = 0 \quad . \quad . \quad . \quad . \quad (41)$$

The analytic method just described necessitates, even when using a first approximation of ϵ, the solving of equations (40) and (41), which is best done by means of approximation. This method does not appear to present any substantial advantages when compared with direct application of formulæ (32), (32′) or (34), since the direct procedure derives from more or less reliable simplifying hypotheses regarding the function ϵ, and gives a synthetic view of the influence of the various parameters upon the efficiency η.

* * *

The following example may serve to elucidate the application of the formulæ and to give a quantitative evaluation, in a typical case, of the influence of the various parameters upon the efficiency.

We assume the same data as in the previous example, *i.e.*, $\Omega^* = 200$ sec.$^{-1}$, $V_0 = 200$ m./sec., $\rho = 0.0835$, II $= 105{,}000$ kgm./sec. Putting as a first approximation $\eta = 0.75$, we find $T = 393.75$ kg.

In calculating the functions ϵ_1 and ϵ_2, we used data from the books of Ferri, Stack and von Doenhoff quoted above, obtaining the following values:—

Values of ϵ_1.

r (m.) \ ξ	0.3	0.4	0.5	0.6	0.7
0.2	0.0544	0.0550	0.0556	0.0565	0.0585
0.3	0.0550	0.0565	0.0581	0.0599	0.0621
0.4	0.0565	0.0584	0.0614	0.0654	0.0724
0.5	0.0578	0.0614	0.0667	0.0730	0.0833
0.6	0.0599	0.0654	0.0730	0.0870	0.1053
0.7	0.0621	0.0704	0.0826	0.1053	0.1299
0.8	0.0654	0.0763	0.0990	0.1282	0.1539
0.9	0.0694	0.0870	0.1163	0.1515	0.1754
1.0	0.0730	0.0980	0.1351	0.1724	0.1818
1.1	0.0794	0.1136	0.1515	0.1786	—
1.2	0.0870	0.1282	0.1695	0.1818	—

ξ	0.7	0.6	0.5	0.4	0.3

Values of ϵ_2.

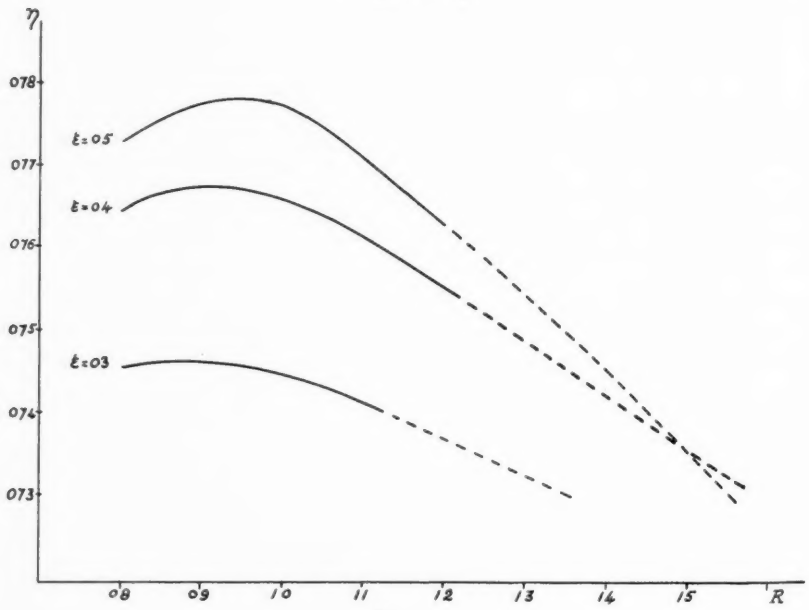

FIG 3.

Applying formula (34) and bearing in mind (20), (24) and (30′), we find the following values for η. (See also Fig. 3.)

η_0	u' (m.) \ ξ	0.3	0.4	0.5	0.6	0.7
0.946	0.8	0.746	0.765	0.773	0.765	0.746
0.956	0.9	0.747	0.768	0.778	0.768	0.747
0.964	1.0	0.745	0.767	0.778	0.767	0.745
0.970	1.1	—	0.762	0.772	0.762	—
0.975	1.2	—	0.756	0.764	0.756	—
0.979	1.3	—	—	—	—	—
0.981	1.4	—	—	—	—	—

From this table we see that the optimum efficiency of the system lies between $R=0.9$ and $R=1$. The optimum ξ is 0.5.[10]

If ϵ, with increase in the speed of the airscrew sections above the speed of sound, were to remain constant and equal to the maximum value 0.1818, we should have for $R=1.5$ the highest radius efficiency, with $\xi=0.4$.

Comparing the system of two counter-rotating airscrews with the corresponding isolated airscrew, we note a marked improvement in optimum efficiency, which rises from 0.727 for the isolated airscrew to 0.778 for the two counter-revolving airscrews. The diameter of optimum efficiency passes from about 2.60 m. for the isolated airscrew to about 2.00 for the counter-revolving airscrews.

In practice, the improvement in efficiency obtainable by substituting two counter-revolving airscrews for a single airscrew may prove less than the calculated value, because the damping out of swirl in the wake is achieved in reality

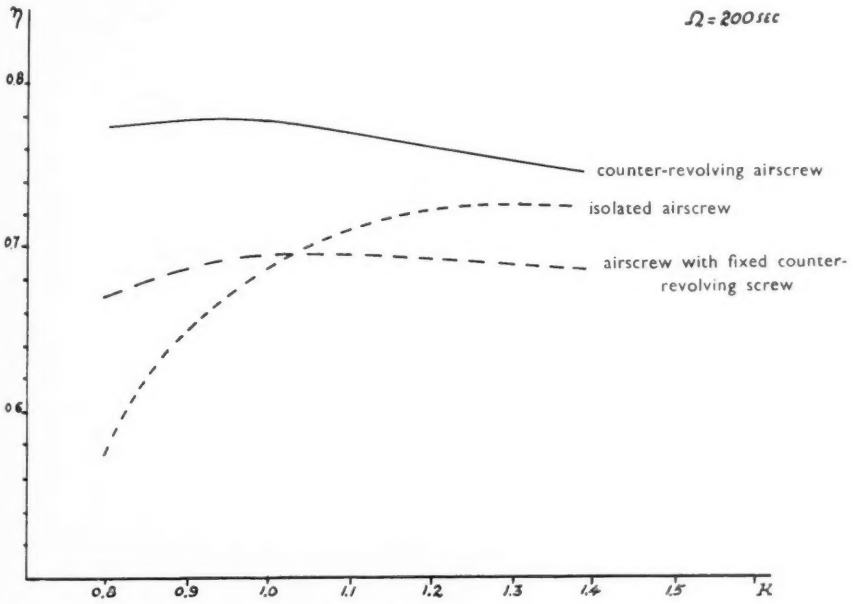

FIG. 4.

by the mixing of the two counter-rotating wakes, which would probably cause a power loss.

The efficiency, however, is still low when compared with airscrews at low Mach numbers, even in the case of counter-revolving airscrews, because of the high peripheral velocity and the great power that must be absorbed. Nor can better results be obtained by immobilising the second airscrew.

Assuming for the latter the constant mean value $\epsilon=0.05128$, we calculate by means of formula (31′), where $x=0$, the efficiency η at various values of R, still keeping the quantities $\Omega=200$ sec.$^{-1}$, $V_0=200$ m./sec., $T=393.75$ kg.

Values of η will be found in the column headed $\eta=0.5$ of the table referring to counter-rotating airscrews.

In the following table and in Fig. 4 are given, together with the η of the "airscrew with fixed counter-revolving screw," values of η relating to the corre-

[10] Note that the values are the same for ξ and $1-\xi$.

sponding isolated airscrew, and those relating to the two counter-revolving airscrews with opposite velocities; in the case under examination, the last-named arrangement seemed to be the best.

$V_0 = 200$ m./sec.; $\Omega = 200$ sec.$^{-1}$; $u = 319$ m./sec.; $\Pi = 105{,}000$ kgm./sec.

Airscrew diameter (m.)	1.6	1.8	2.0	2.2	2.4	2.6[11]	2.8[11]
Efficiency of single airscrew...	0.574	0.650	0.693	0.714	0.725	0.727	0.725
Efficiency of two counter-rotating airscrews $\xi = 0.5$...	0.773	0.778	0.778	0.772	0.764	—	—
Efficiency of airscrew with fixed counter-screw $x = 0$...	0.670	0.687	0.695	0.697	0.696	—	—

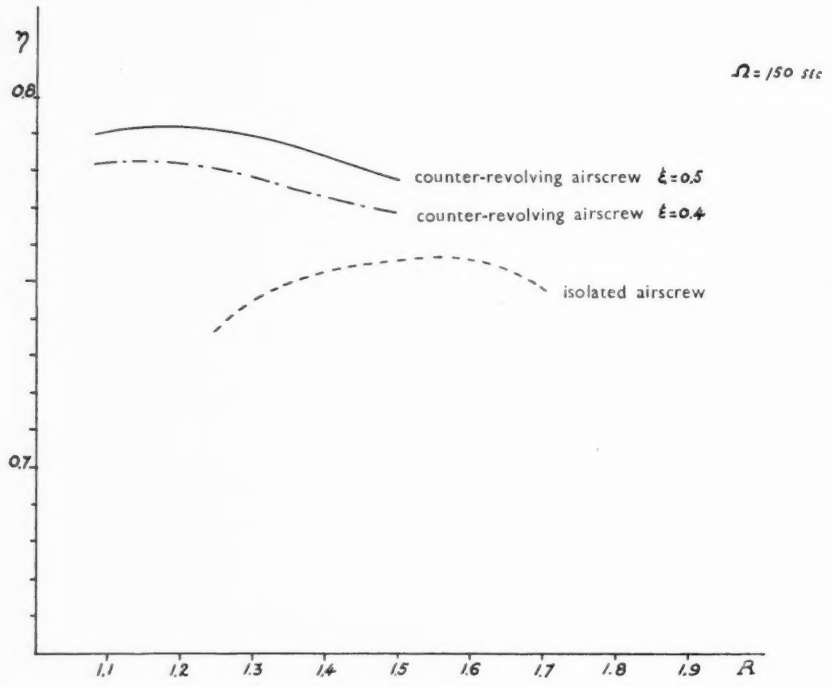

FIG. 5.

Since the ϵ have been deduced from the same source, the relative value of η corresponding to the three propulsive systems is a nearer approximation than the absolute value. The reliability of the latter depends upon the degree of applicability to the case under examination of the experimental results utilised, and upon the accuracy of their approximations.

Reducing Ω from 200 sec.$^{-1}$ to 150 sec.$^{-1}$, while the other data u, ρ, V_0, Π, remain constant, we obtain the results summarised in the following table and in Fig. 5.

[11] The values 0.727, 0.725 are obtained by exterpolating the experimental results for the blade-tips, which in the case of an isolated airscrew have less influence on the efficiency than in the other two cases, owing to the different distribution of along the blade.

$V_0 = 200$ m./sec. ; $\Omega = 150$ sec.$^{-1}$; $u = 319$ m./sec. ; $\Pi = 105{,}000$ kgm./sec.

Airscrew diameter (m.) ...	2.20	2.40	2.60	2.80	3.00	3.20	3.40
Efficiency of single airscrew...	—	—	0.745	0.754	0.756	0.756	0.749
Efficiency of two counter-rotating airscrews $\xi = 0.5$...	0.791	0.792	0.790	0.785	0.779	—	—
Efficiency of two ditto for $\xi = 0.4$	0.782	0.782	0.779	0.775	0.769	—	—

In this case also the best of the propulsive systems examined is that of two counter-revolving airscrews with opposite angular velocities. Comparing this table with the preceding one, we see the whole advantage obtained by reducing the angular velocity ; the maximum efficiency rises from 0.778 for $\Omega = 200$ sec.$^{-1}$ to 0.792 for $\Omega = 150$ sec.$^{-1}$. Note also that by diminishing the angular velocity we lessen the gain in efficiency obtained by substituting two counter-revolving airscrews for the isolated airscrew.

The choice of propulsive system cannot be based solely on efficiency, but must also take into consideration the structure of the aeroplane and the uses for which it is built—factors which may lead to modifications in efficiency.

The system of two counter-revolving airscrews will be slightly heavier than that of the isolated airscrew, but on the other hand it has the advantage that the diameter can be reduced, giving an indirect gain in weight.

The counter-revolving system is undoubtedly more complicated, especially when it is necessary to use variable-pitch airscrews which have to be regulated in flight. On the other hand, it eliminates torque, with evident constructional and aerodynamic advantages and improvement in the handling qualities of the aeroplane on the take-off and in flight.

* * *

We have seen that the efficiency η of a helicoidal propulsor for a high-speed aeroplane can be expressed with adequate approximation as a function of the quantities ρ, Π, V_0, R, Ω, u, only when R, V_0, Ω, also define the form of the propulsor, as is usually the case.

According to Buckingham's theorem,[12] η could be expressed in the form :—

$$\eta = \eta\left(\frac{\Pi\Omega^2}{\rho V_0^5} \cdot \frac{V_0}{u} \cdot \frac{V_0}{R\Omega}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad (42)$$

For each family of propulsors and for each set of three values of the three independent adimensional variables, there will be a determined value of η. Keeping the first two parameters—which obviously contain in themselves all the data of the problem—invariable, we search, by the method explained above, for the value $\bar{\gamma}$ of $V_0/R\Omega$ to which the propulsive system giving optimum η corresponds.

We can thus construct for each family of propulsors the functions :—

$$\bar{\gamma} = \bar{\gamma}\left(\frac{\Pi\Omega^2}{\rho V_0^5} \cdot \frac{V_0}{u}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad (43)$$

which rapidly gives, by means of suitable graphic or numerical representations, a simple and practicable means of finding the best propulsive system.

* * *

I wish to express my best thanks to my eminent colleague, Professor E. Pistolesi, for his advice in connection with the present article.

[12] c.f., for example, R. Doherty and E. G. Keller, Mathematics of Modern Engineering, Chapter V.

AN ANALYSIS OF THE AERODYNAMIC CHARACTERISTICS OF SPLIT FLAPS.

By A. P. West, A.F.R.Ae.S.

Introduction.

During the past few years an extensive amount of experimental data on split flaps has been made available to the aircraft industry, through the publications of aeronautical research laboratories, both in this country and abroad. In general, each publication deals with one particular aspect of the problem, and when the effect of wing flaps on the performance of an aircraft is being estimated a certain amount of difficulty may be experienced in deciding which of the many reports available gives results most readily applicable to the case being considered; and what allowances, if any, should be made for wing taper, flap cut-out, fuselage, etc.

In this report the available data has been analysed with a view to answering these questions, and presented in such a form that it may be readily applied to determine the most probable change in the aerodynamic characteristics of a wing that may be expected from the use of this type of flap.

From the appendix an estimate of the accuracy of the method can be obtained, as a comparison with full-scale data is given for lift and drag, and for the other flap characteristics the original curves have been reproduced.

Nomenclature.

$C_L = L/qAw$, lift coefficient of wing with flaps up.
ΔC_L = increase in C_L due to flaps.
$C_D = D/qAw$, drag coefficient of wing with flaps up.
ΔC_D = increase in C_D due to flaps.
Aw = gross wing area.
$q = \frac{1}{2}\rho v^2$, dynamic pressure.
$\Delta C_{Di} = \{ (C_L + \Delta C_L)^2 - C_L^2 \} / \pi R$. The theoretical minimum value for increase in induced drag due to flaps.
R = aspect ratio.
$C_{De} = C_D - C_L^2/\pi R$, effective parasite drag coefficient.
ΔC_{De} = increase in the effective parasite drag coefficient due to flaps.
$\alpha_a{}^\circ$ = absolute angle of attack, *i.e.*, angle of attack measured from the no lift angle.
Af/Aw = ratio of the wing area over which the flap extends to the gross wing area. Assuming the flap to extend across the body.
$\Delta' C_L$ = increase in C_L due to full span flaps on a wing of rectangular plan form, aspect ratio 6, at $\alpha_a = 9^\circ$.
$\Delta' C_{De}$ = increase in C_{De} due to full span flaps on a wing of rectangular plan form, aspect ratio 6, at $\alpha_a = 9^\circ$.
$F(\alpha_a) \cdot f(\alpha_a)$ = angle of attack correction factors for lift and drag respectively.
$f(A)$ = aspect ratio correction factor to $\Delta' C_L$.
$f\Delta C_L = \Delta' C_L \times f(A)$.
$f(b)$ = partial span correction factor to $f\Delta C_L$.
$f(t)$ = wing taper correction factor to $f\Delta C_L$ for partial span flaps.
$Chf = Hf/(q \cdot Cf \cdot Sf)$, flap hinge moment coefficient.
$Cnf = Nf/(q \cdot Sf)$, flap normal force coefficient.
$Cm\frac{1}{4}c = M\frac{1}{4}c/(q \cdot Aw \cdot c)$, wing pitching moment about $\frac{1}{4}$ chord point of mean geometric chord.

$\Delta Cm\frac{1}{4}c$ = increase in $Cm\frac{1}{4}c$ due to full span flap.
Hf = flap hinge moment about flap hinge.
Nf = flap normal force.
$M\frac{1}{4}c$ = wing pitching moment about $\frac{1}{4}$ chord point of mean geometric chord.
Sf = flap area.
Cf = flap chord.
C = mean geometric wing chord.

The flap chord is expressed as a fraction of the mean chord of the portion of wing over which the flap extends.

METHOD OF ANALYSIS.

In order to obtain the most probable change in aerofoil characteristics due to the flap, mean values based on all the available data have been used throughout and increments of the various characteristics plotted, so that they may be added directly to the basic wing being considered and scale effects reduced to a minimum. In the case of drag the total increase due to the flap has been split up as follows: –

$$\Delta C_D = \Delta C_{Di} + \Delta C_{De} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

when

$$\Delta C_{Di} = (\Delta C_L / \pi R) \left[2 C_L + \Delta C_L \right] \quad . \quad . \quad . \quad . \quad (2)$$

which is the theoretical minimum value for the increase in induced drag. C_L being the lift coefficient for the plain wing, and ΔC_L the increase due to the flap.

For both lift and drag a basic set of conditions has been taken (see §1), on which the effects of change in flap span, angle of attack, etc., have been investigated; and when necessary, correction factors obtained.

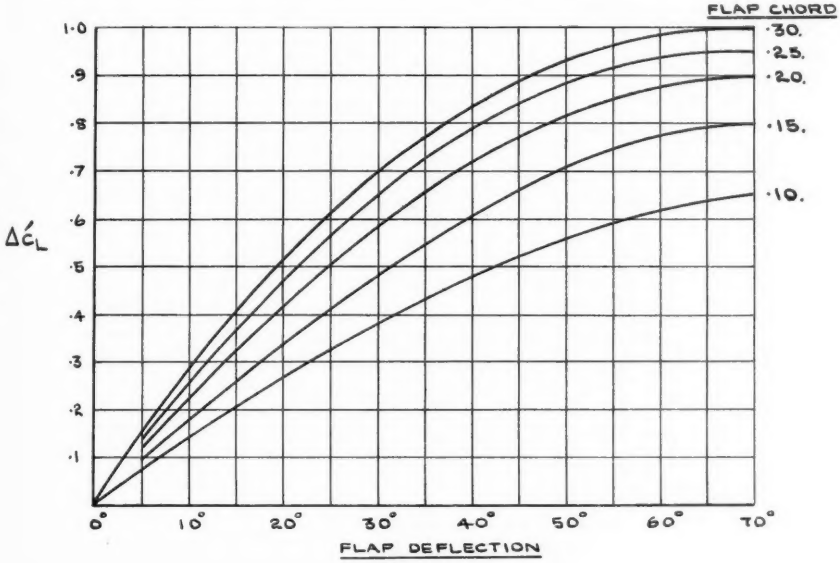

FIG. 1.

DISCUSSION AND DESCRIPTION OF FIGURES.

§1. *Basic curves for lift and drag. Ref.* 1, 2, 4, 10.

In Figs. 1 and 6 mean values of lift and drag coefficients at 9° absolute angle of attack are plotted against flap deflection. These values apply to wings of

Clark Y section, rectangular plan form, aspect ratio 6, with full span flap, and are considered as the basis from which the actual values of the lift and drag may be obtained.

§2. *Aspect ratio. Ref.* 14.

The theoretical value of the lift coefficient of a wing with a plain flap is:—

$$C_L = a_1 a_a + a_2 \delta f$$

when $a_1 = dC_L/d\alpha$ = the slope of the wing lift curve.

$a_2 = dC_{Lf}/d\delta_f$ = the slope of the lift increase due to the flap.

a_1 and a_2 are functions of aspect ratio, but the ratio a_1/a_2 is independent of same. Hence the increase in lift due to plain flap is dependent on aspect ratio, and it will be assumed that the above relationship is valid for the split flap. Considering any aspect ratio, R, and aspect ratio 6. We have: —

$$(a_1)_R/(a_1)_6 = (a_2)_R/(a_2)_6$$

Taking the theoretical relationship

$$(a_1)_\infty/(a_1)_R = 1 + (a_1)_\infty/\pi R$$

and putting

$$(a_1)_\infty = 1.8\,\pi$$

gives

$$(a_1)_R = 5.65/(1 + 1.8/R)$$

and as

$$(a_1)_6 = 4.35 \text{ per radian}$$

the required correction factor becomes

$$f_{(A)} = (a_2)_R/(a_2)_6 = 0.0227\,(1 + 1.8/R) \qquad \text{(see Fig. 2)}$$

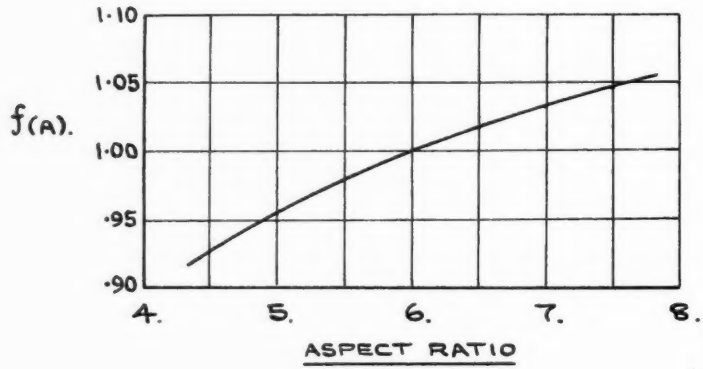

FIG. 2.

§3. *Angle of attack.*

The mean values of the increments of lift and drag coefficients obtained from the references used in constructing Figs. 1, 3, 4 and 6, were plotted against absolute angle of attack for a range of flap chords, and it was noticed that the slope of the curves for different values of flap chord was approximately the same at a constant flap deflection; so that by taking a mean curve an angle of attack correction factor is obtained which is independent of flap chord. In the case of the lift coefficient this factor is small, except for small flap deflections (see Fig. A in the Appendix), and as it is seldom necessary to investigate the characteristics of a flap under these conditions it is not considered that it need be included in

routine calculations. The corresponding factor for drags is practically independent of flap deflection for both full span and partial span flaps. For partial span flaps with spans up to 0.8 of the wing span the factor is negligible and the drag expression has been simplified accordingly. If full span flaps have to be considered the factor is of more importance, and is given by Fig. B in the Appendix.

§4. *Wing taper. Full span flaps. Ref.* 3.

There is an increase in lift coefficient on a tapered wing with full span flap over that obtained from a similar wing of rectangular plan form. The correction being the same whether the flap chord of the tapered wing is the same per cent.

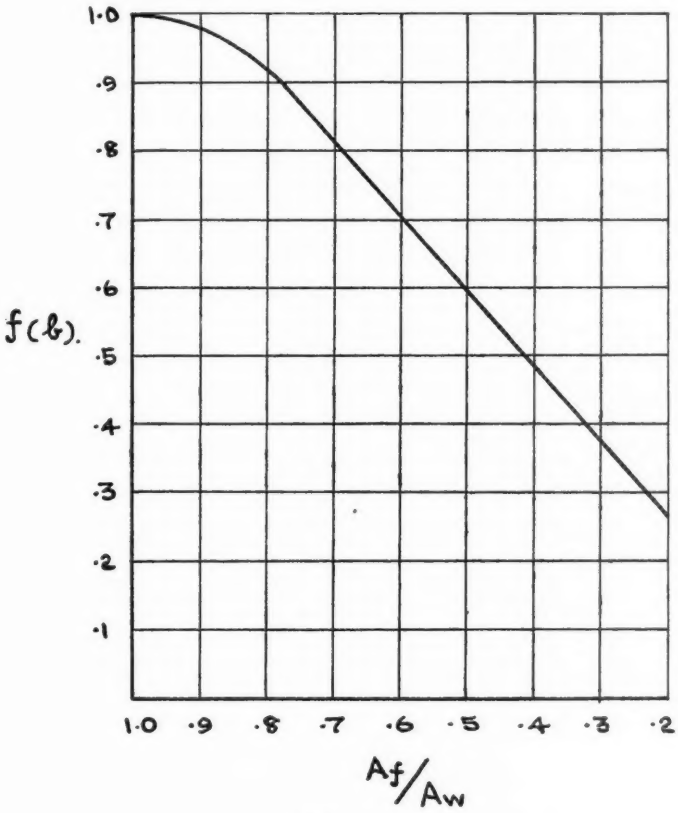

FIG. 3.

of the main wing chord over the whole span (*i.e.*, if the flap chord tapers with the wing chord), or if the flap chord is a constant and the same per cent. of the wing chord at the flap semi-span as on the rectangular wing. If flaps of constant chord are used on a wing of tapered plan form the effective parasite drag due to the flap is the same as on a wing of rectangular plan, but if the flap chord tapers with the wing chord there is a reduction in drag which appears to be about the same at all flap deflections. Both effects are slight, except on wings having very high tapers, and it is not considered that their magnitude justifies their inclusion in the lift and drag expressions.

§5. *Flap span. Ref.* 1.

For the lift increments this factor is plotted, in Fig. 3, against the ratio of the area over which the flap extends to the gross wing area, while for the drag increments the factor was found to be given directly by the same ratio, and no curve was required. It should be noted that when estimating this ratio the flap is assumed to extend across the body in all cases, as a further correction factor takes flap cut-out and body position into account.

§6. *Wing taper. Partial span flaps. Ref.* 3, 12.

It was found that wing taper caused a slight reduction in the lift of a wing having a partial span flap, and the appropriate correction factor is given in Fig. 4, but no such reduction was noticed in the case of the drags. This factor may be used for partial span flaps with spans up to 0.8 of the total wing span.

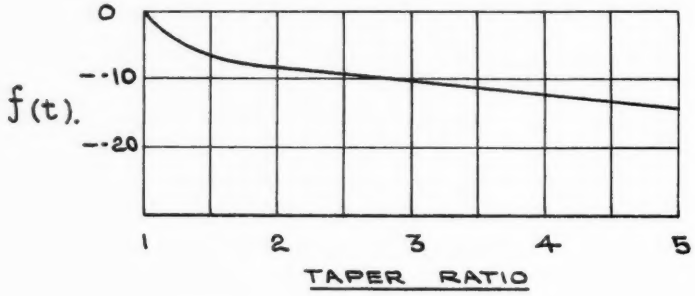

FIG. 4.

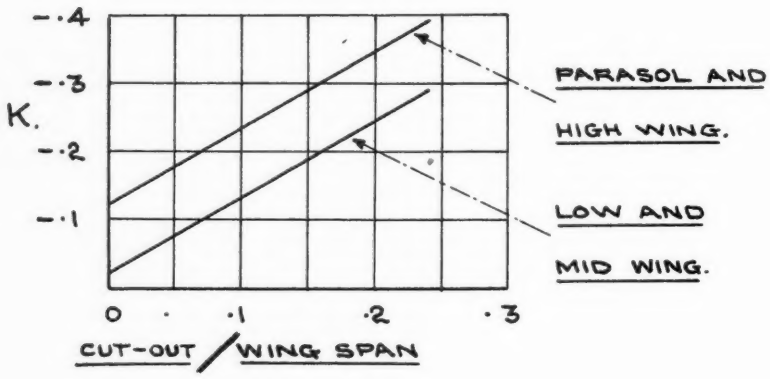

FIG. 5.

§7. *Body position and flap cut-out. Ref.* 1, 3, 7.

The effect on lift of the addition of a body is assumed to vary only with the relative position of body and wing and this factor had been combined, in Fig. 5, with the correction for flap cut-out, expressed as a fraction of the wing span. When calculating this factor no flap cut-out is to be taken on high and mid-wing monoplanes having the flap extending to the side of the body.

Similar drag correction factors were derived from the references given, but on a preliminary comparison with full-scale results it was found that the corrected

drag increments from the curves were consistently high; except in one case, that of a low wing monoplane having an unusually large flap cut-out extending across the wing centre section (0.24 of the wing span). From this it was concluded that the effect of a body in reducing the drag of a flap was greater than shown by the model data, and masked any effect of flap cut-out near the body. A constant reduction of 0.2 $\Delta' C_{De}$ for the effect of the body appeared to give fair agreement with full-scale results for flap cut-outs up to 0.24 of the wing span, and this factor has been used in the drag expression in place of the factor derived from the references given above.

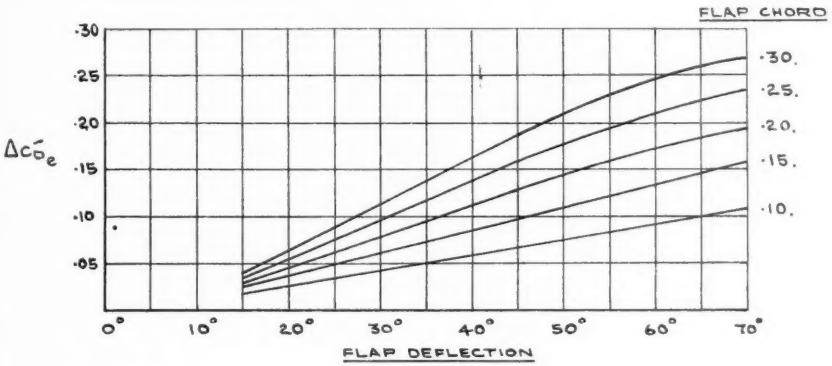

FIG. 6.

§8. *The lift and drag expressions.*

The increment of lift coefficient due to the flap may now be expressed as follows:—

$$\Delta C_L = f \Delta C_L [f(b) + f(t) + K]$$

when

$$f\Delta C_L = \Delta' C_L \times f_{(A)} \quad . \quad . \quad . \quad . \quad . \quad (3)$$

and the increment of effective parasite drag coefficient as:—

$$\Delta C_{De} = \Delta' C_{De} [Af/Aw - 0.20] \quad . \quad . \quad . \quad . \quad (4)$$

The original forms of these expressions, which allowed for the inclusion of an angle of attack correction factor, are given in the Appendix.

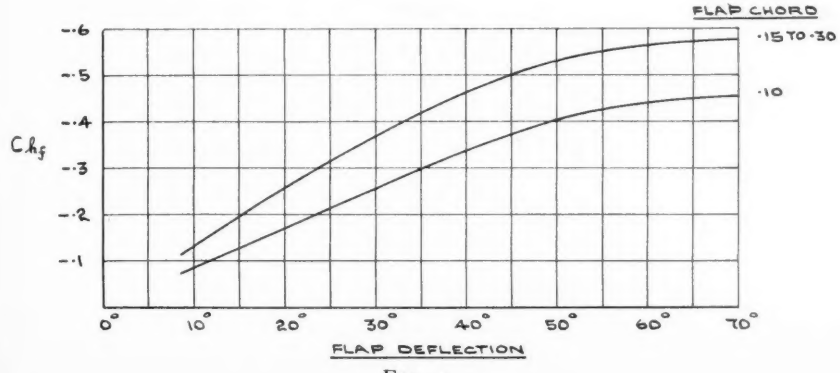

FIG. 7.

It should be noted that when dealing with tapered wings the flap chord is expressed as a fraction of the mean chord of the portion of the wing over which the flap extends.

§9. The mean values for flap hinge moment, flap normal force, and increment of wing pitching moment coefficients are given in Figs. 7, 8, 9, respectively. The original curves, which were based on full-scale and model data, are given in the Appendix to enable an estimate of the accuracy of the work to be obtained.

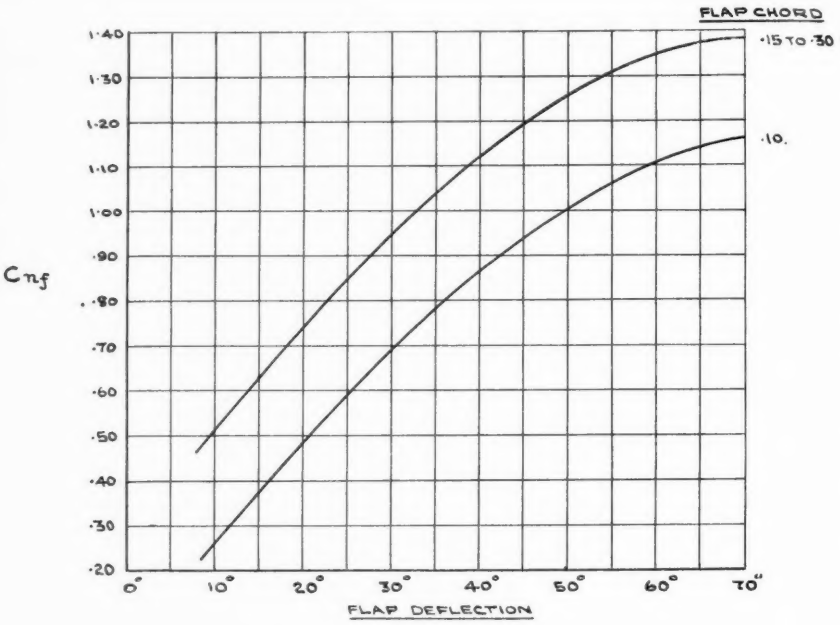

FIG. 8.

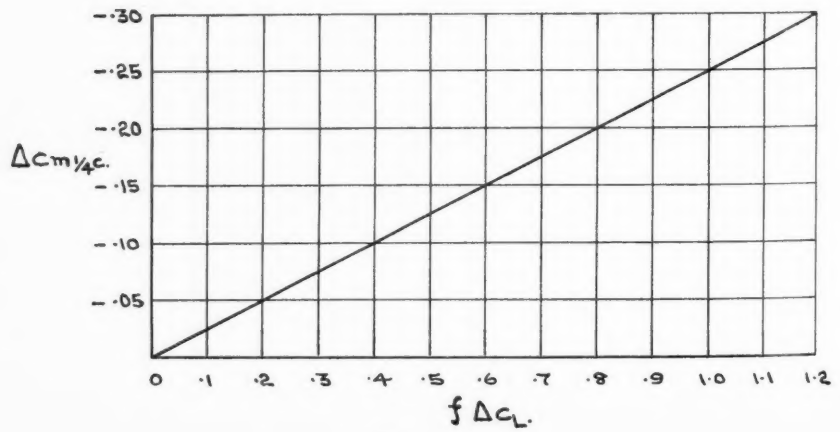

FIG. 9.

As pointed out by Mr. A. E. Russell (see Ref. 15), the equation to the increment of wing pitching moment due to the flap is given by $\Delta Cm\frac{1}{4}c = 0.25\, f\Delta C_L$ (see Fig. 9); hence, in all cases, the increment of lift due to the flap may be considered as applied at 0.5 of the mean chord of the portion of the wing over which the flap extends. When carrying out balance calculations for the whole aircraft it will be found convenient to use this relationship, but should $\Delta Cm\frac{1}{4}c$ be required the values from Fig. 9, which apply to wings having full span flaps, must be multiplied by the ratio of the wing area over which the flap extends to the gross wing area, if partial span flaps are being considered. On tapered wings this increase in wing pitching moment coefficient due to the flap is assumed to act at the $\frac{1}{4}$ chord point of the mean chord of the portion of the wing over which the flap extends.

§10. *Application of the Curves.*

As an example on the use of the method the following case will be considered:—
Mid-wing monoplane, with flaps extending to side of fuselage.

Aspect ratio	6.8
Wing taper	1.6 : 1
Flap deflection	65°
Flap chord	0.15 Cw
Af/Aw	0.67
C_L flaps up	1.5

FLAP CHARACTERISTICS.

1. Increase in lift coefficient.

$$\Delta C_L = f\Delta C_L\,[f(b) + f(t) + K]$$

when

$$f\Delta C_L = \Delta' C_L \times f_{(A)}$$

$f\Delta C_L = 0.79 \times 1.025 = 0.81$ (Figs. 1 and 2)

$[f(b) + f(t) + K] = 0.784 - 0.07 - 0.02 = 0.694$ (Figs. 3, 4 and 5)

$\therefore\ \Delta C_L = 0.81 \times 0.694 = 0.56.$

2. Increase in drag coefficient.

$$\Delta C_D = \Delta C_{Di} + \Delta C_{De}$$

when

$$\Delta C_{Di} = (\Delta C_L/\pi R)\,[2\,C_L + \Delta C_L]$$

and

$$\Delta C_{De} = \Delta' C_{De}\,[Af/Aw - 0.20]$$

$\Delta C_{Di} = 0.027 \times 3.56 = 0.096$

$\Delta C_{De} = 0.145 \times 0.47 = 0.068$ (Fig. 6)

$\therefore\ \Delta C_D = 0.096 + 0.068 = 0.164$

3. (*a*) Flap hinge moment coefficient $= -0.57$. (Fig. 7)

(*b*) Flap normal force coefficient $= 1.37$. (Fig. 8)

4. Increase in wing pitching moment coefficient about $\frac{1}{4}$ chord point of mean chord of portion of wing over which flap extends $= -0.20 \times 0.67 = -0.134$ (Fig. 9).

APPENDIX.

The full expressions for the increase in the lift and effective parasite drag coefficients due to the flaps may be written as follows:—

$$\Delta C_L = F\Delta C_L\,[f(b) + f(t) + K]$$

when

$$F\Delta C_L = [\Delta' C_L \times f_{(A)}] + F(a_a) \quad . \quad . \quad . \quad . \quad (5)$$

$$\Delta C_{De} = \{\Delta' C_{De} + f(a_a)\}\ \{Af/Aw - 0.20\} \quad . \quad . \quad (6)$$

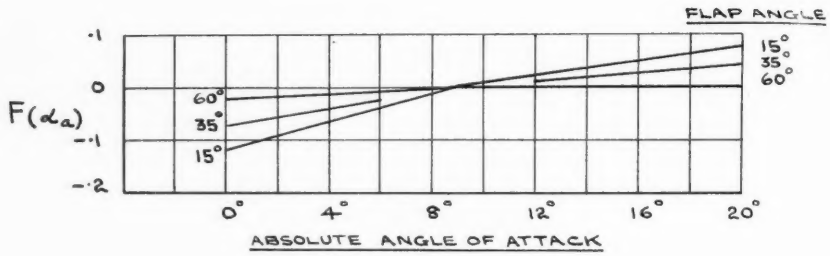

FIG. A (APPENDIX).

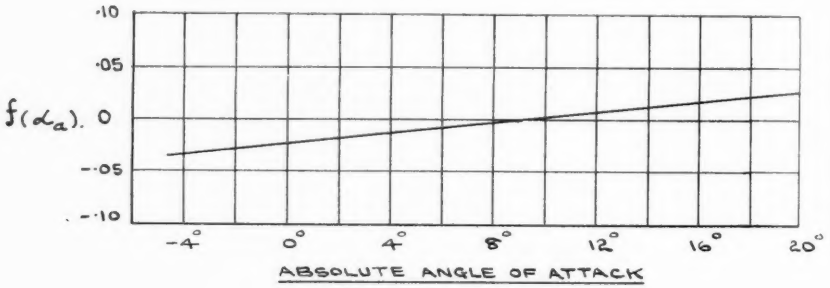

FIG. B (APPENDIX).

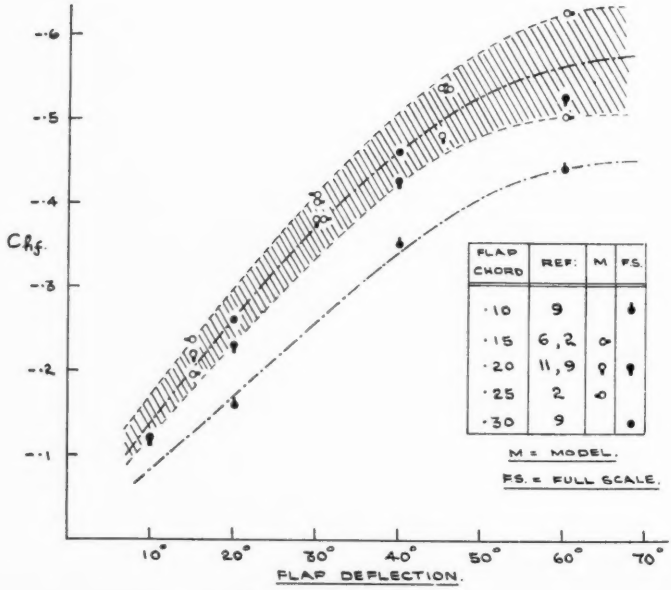

FIG. C (APPENDIX).

The correction factors for angle of attack are given in Figs. A and B. The former applies to both full and partial span flaps, but the drag factor given in Fig. B should only be used when full span flaps are being considered, as for partial span flaps, with spans up to 0.8 of the total wing span, this factor is negligible.

It will be noted that most of the analysis is based on data obtained from wind tunnel model tests on wings of Clark Y section, and although the values of increment of lift and drag were found to be to some extent dependent on aerofoil section, it was not found possible to obtain a section correction factor. It is not considered that this introduces a very large error when dealing with partial span flaps on orthodox aerofoils.

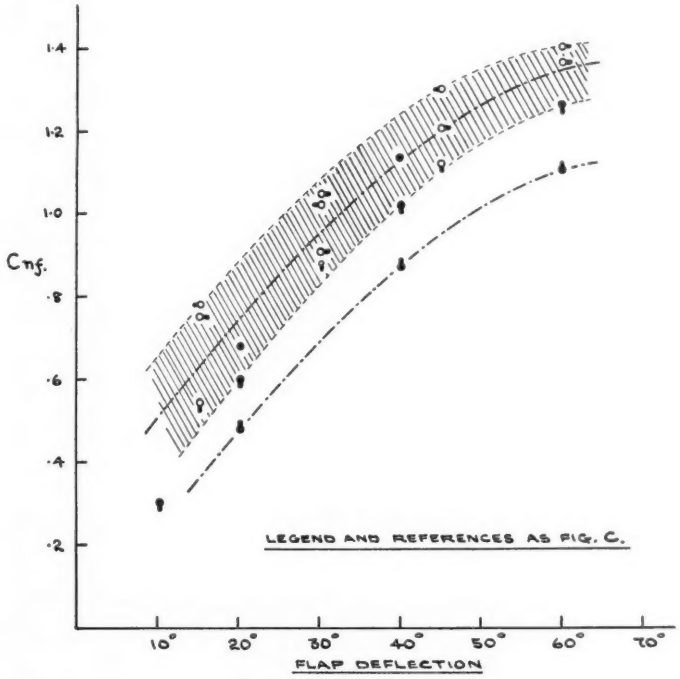

FIG. D (APPENDIX).

Figs. C, D and E are the original curves from which Figs. 7, 8 and 9 were constructed. They are based on full-scale and model data, and are reproduced here to enable an estimate of the probable accuracy of the latter curves to be made.

The attached table compares the increments of lift and drag coefficients given by this report with the actual recorded increments obtained from an analysis of full-scale tests.

The lift increment curves were derived entirely from model data, and it is considered that the agreement with full scale is as good as could be expected in view of the number of variables involved. In the case of the drags it should be noted that a body correction constant had to be introduced to give agreement with full-scale results (see paragraph 7). This constant was obtained by comparing the first four full-scale drags given in the above table with the results given by the curves, and subsequent comparison with the remaining full-scale results did not indicate any modification to the constant.

Lift and Drag.

Comparison with Full Scale.

Report No.	Wing Taper	Flap Chord.	Flap Angle.	Flap Cut-out.	C_L Flaps Up.	Af/Aw	Wing Position.	Actual. $\triangle C_L$	Actual. $\triangle C_{De}$	Estimated. $\triangle C_L$	Estimated. $\triangle C_{De}$	Error in $\triangle C_L$	Error in $\triangle C_{De}$	% Error in C_L Total.
B.A. 1411 (Flight)	1·5 : 1	.11	90°	0	1.22	.473	Low	.40	.04	.35	.04	− 05	0	−3
	2.0 : 1	.23	45°	.24	1.46	.716		.50	.06	.39	.075	−.11	+·015	−6
	1.6 : 1	.20	45°	.078	1.24	.536		.32	.04	.36	.04	+.04	0	+3
	3 0 : 1	.10	70°	0	1.36	.755		.56	.07	.52	.06	−.04	- .01	−2
	1·75 : 1	.15	77°	0	1.26	.656		.60	.07	.55	.08	−.05	+ 01	−3
T.N. 475 (F.S. Tunnel)	1 : 1	.20	59°	.10	1.47	1.0		.62	.12	.74	.13	+.12	+.01	+6
T.R. 539 (F.S. Tunnel)	1 : 1	.10	60°	.09	1.46	.90	Parasol	.50	.06	.46	.06	−.04	0	−2
	1 : 1	.20	60°	09	1.46	.90		.72	.12	.66	.12	−.06	0	−3
	1 : 1	.30	40°	.09	1.46	.90		.70	.13	.63	.11	−.07	− 02	−3

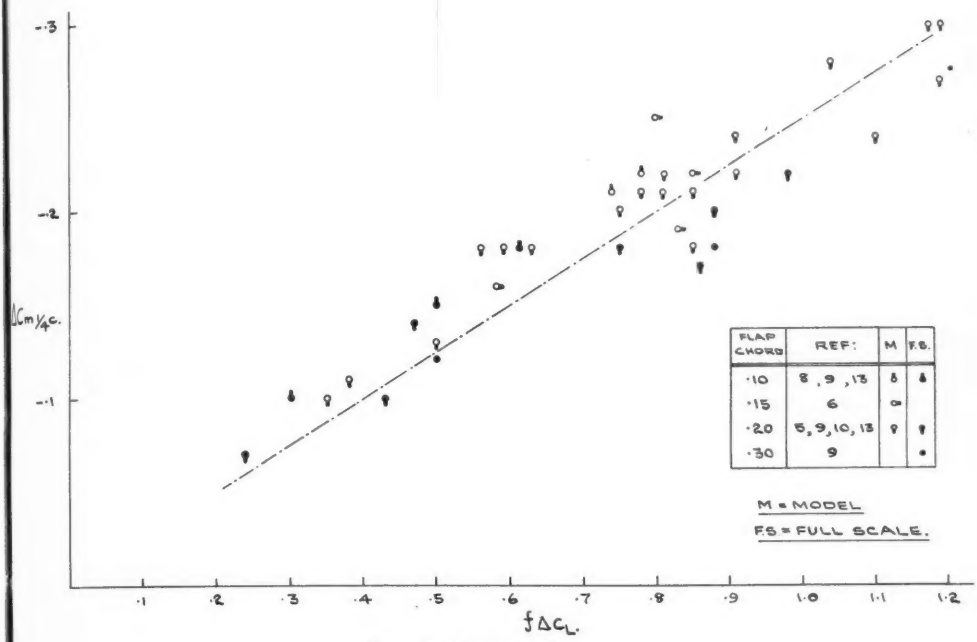

FIG. E (APPENDIX).

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CLAMPED RECTANGULAR PLATES WITH A CENTRAL CONCENTRATED LOAD.*

By Dana Young,† Storrs, Conn.

A general method of solution for rectangular plates with clamped edges and any kind of loading has been developed by Professor S. P. Timoshenko (1).‡ The present paper gives the results of calculations using this method for the maximum deflection, moment, and edge shears for rectangular plates of various proportions with all four edges clamped and loaded by a single concentrated load at the centre. Similar data for a clamped rectangular plate with a uniformly distributed load have been given by I. A. Wojtaszak and also T. H. Evans (2). A report of an experimental investigation of this problem with some analytical results has been given by R. G. Sturm and R. L. Moore (3).

The notations used are as follows:—

a = length of plate in the x-direction
b = length of plate in the y-direction
h = thickness of plate
E = modulus of elasticity of the plate material
μ = Poisson's ratio. In the numerical calculations this is assumed equal to 0.3
$D = \dfrac{Eh^3}{12\,(1-\mu^2)}$ is the flexural rigidity of the plate
P = central concentrated load
M = bending moment per unit length of plate
Q = shearing force per unit length of plate
R = total vertical reaction along one edge of plate
w = deflection of plate at any point

$$\alpha_m = \frac{m\pi b}{2a}$$

$$\beta_m = \frac{m\pi a}{2b}$$

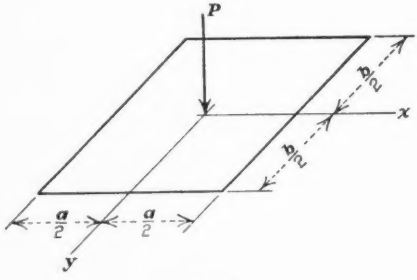

Fig. 1

The origin of co-ordinates is taken at the centre of the plate as shown in Fig. 1. The general procedure as applied to this particular problem is as follows:—

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‡ Numbers in parentheses refer to the Bibliography at the end of the paper.

For a plate with no distributed lateral load, the deflection surface is governed by the differential equation

$$\frac{\partial^4 w}{\partial x^4} + 2\frac{\partial^4 w}{\partial x^2 \partial y^2} + \frac{\partial^4 w}{\partial y^4} = 0 \quad . \quad . \quad . \quad . \quad . \quad (1)$$

To solve this equation for the given problem, the known solution for a simply supported plate with a central concentrated load is combined with that for a simply supported plate with distributed bending moments applied along the edges. The applied edge moments are then so determined that the slope at the boundaries is zero; that is, take

$$w = w_1 + w_2 + w_3 \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where

$$w_1 = \frac{Pa^2}{2\pi^3 D} \sum_{m=1,3,5\ldots} \frac{1}{m^3} \cos\frac{m\pi x}{a} \left[\left(\tanh \alpha_m - \frac{\alpha_m}{\cosh^2 \alpha_m} \right) \right.$$

$$\left. \cosh\frac{m\pi y}{a} - \sinh\frac{m\pi y}{a} - \tanh \alpha_m \frac{m\pi y}{a} \sinh\frac{m\pi y}{a} + \frac{m\pi y}{a}\cosh\frac{m\pi y}{a} \right] . \quad (3)$$

is the solution for a simply supported rectangular plate with a central concentrated load (4). Also where

$$w_2 = -\frac{a^2}{2\pi^2 D} \sum_{m=1,3,5\ldots} A_m \frac{(-1)^{\frac{m-1}{2}}}{m^2 \cosh \alpha_m} \cos\frac{m\pi x}{a} \left[\frac{m\pi y}{a}\sinh\frac{m\pi y}{a} \right.$$

$$\left. - \alpha_m \tanh \alpha_m \cosh\frac{m\pi y}{a} \right] \quad . \quad . \quad . \quad . \quad . \quad (4)$$

and

$$w_3 = -\frac{b^2}{2\pi^2 D} \sum_{m=1,3,5\ldots} B_m \frac{(-1)^{\frac{m-1}{2}}}{m^2 \cosh \beta_m} \cos\frac{m\pi y}{b} \left[\frac{m\pi x}{b}\sinh\frac{m\pi x}{b} - \beta_m \tanh \beta_m \cosh\frac{m\pi x}{b} \right] \quad (5)$$

are the deflections for a simply supported plate with moments applied along the pairs of edges $y = \pm b/2$ and $x = \pm a/2$, respectively (5). These applied edge moments are given by

$$(M_y)_{y=\pm b/2} = \sum_{m=1,3,5\ldots} (-1)^{\frac{m-1}{2}} A_m \cos\frac{m\pi x}{a} \quad . \quad . \quad . \quad (6)$$

$$(M_x)_{x=\pm a/2} = \sum_{m=1,3,5\ldots} (-1)^{\frac{m-1}{2}} B_m \cos\frac{m\pi y}{b} \quad . \quad . \quad . \quad (7)$$

in which the Fourier-series coefficients A_m and B_m are to be determined from the condition that the slope at the boundaries is zero. Thus taking $\left(\frac{\partial w}{\partial y}\right)_{y=b/2} = 0$ and expressing the terms containing $\frac{m\pi x}{b}\sinh\frac{m\pi x}{b}$ and $\cosh\frac{m\pi x}{b}$ by a cosine series, we obtain

$$\frac{Pa}{2\pi^2 D} \sum_{m=1,3,5\ldots} \frac{1}{m^2} \cos\frac{m\pi x}{a} \frac{\alpha_m \tanh \alpha_m}{\cosh \alpha_m}$$

$$+ \frac{a}{2\pi D} \sum_{m=1,3,5\ldots} A_m \frac{(-1)^{\frac{m-1}{2}}}{m} \cos\frac{m\pi x}{a} \left(\tanh \alpha_m + \frac{\alpha_m}{\cosh^2 \alpha_m} \right)$$

$$+ \frac{4a^2}{\pi^2 b D} \sum_{m=1,3,5\ldots} \frac{B_m}{m^3} \sum_{i=1,3,5\ldots} \frac{i(-1)^{\frac{i-1}{2}}}{\left(\frac{a^2}{b^2} + \frac{i^2}{m^2}\right)^2} \cos\frac{i\pi x}{a} = 0 \quad . \quad . \quad (8)$$

This relation holds for any particular value of the cosine term, say $\cos \frac{k\pi x}{a}$

Therefore, the summation signs may be dropped and this cosine term cancelled, thus obtaining

$$A_k \frac{1}{k}\left[\tanh \alpha_k + \frac{\alpha_k}{\cosh^2 \alpha_k}\right] + \frac{8\,ak}{\pi b} \sum_{m=1,3,5\ldots} \frac{B_m}{m^3} \frac{1}{\left(\frac{a^2}{b^2} + \frac{k^2}{m^2}\right)^2}$$

$$= -P \frac{(-1)^{\frac{k-1}{2}}}{\pi k^2} \frac{\alpha_k \tanh \alpha_k}{\cosh \alpha_k} \quad . \quad . \quad . \quad . \quad . \quad (9)$$

Similarly, for zero slope at $x = \frac{a}{2}$ is obtained

$$B_k \frac{1}{k}\left[\tanh \beta_k + \frac{\beta_k}{\cosh^2 \beta_k}\right] + \frac{8\,bk}{\pi a} \sum_{m=1,3,5\ldots} \frac{A_m}{m^3} \frac{1}{\left(\frac{b^2}{a^2} + \frac{k^2}{m^2}\right)^2}$$

$$= -P \frac{(-1)^{\frac{k-1}{2}}}{\pi k^2} \frac{\beta_k \tanh \beta_k}{\cosh \beta_k} \quad . \quad . \quad . \quad . \quad . \quad (10)$$

Equations (9) and (10) are used to determine the coefficients A_k and B_k. They form a double-infinite system of simultaneous equations which may be solved approximately by neglecting the higher terms. Thus for a plate with the proportions $b/a = 1.2$, from Equation (9) the system of Equations (11), given in Table 1, is obtained by assigning to k the values 1, 3, 5, . . . , in turn. Similarly, from Equation (10) the system of Equations (12), given in Table 2, is derived.

Neglecting terms higher than those given, Equations (11) and (12) (Tables 1 and 2) may be solved by successive approximations. For the first approximation the terms to the right of the stepped line are neglected. For the second approximation, the values of A_3 to A_9 and B_3 to B_9 found from the first approximation are substituted in the terms to the right of the stepped line and the system solved again. This process is repeated as many times as necessary. Three or four approximations have been found sufficient for these calculations. Using this procedure, the coefficients for rectangular plates of several proportions were calculated. The results are given in Table 3.

The deflection at the centre is then found from Equations (2), (3), (4), and (5) and may be reduced to the form

$$(w)_{\substack{x=0 \\ y=0}} = \alpha \frac{Pa^2}{Eh^3} \quad . \quad . \quad . \quad . \quad . \quad . \quad (13)$$

The maximum edge moment is found from Equation (7) to be

$$(M_x)_{\substack{x=a/2 \\ y=0}} = \sum_{m=1,3,5\ldots} (-1)^{\frac{m-1}{2}} B_m = -\beta P \quad . \quad . \quad . \quad (14)$$

in which the negative sign is used for a moment which bends the plate concave downward.

The maximum edge shear occurs at the centre of the long side and is given by

$$(Q_x)_{\substack{x=a/2 \\ y=0}} = -D \frac{\partial}{\partial x}\left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2}\right)_{\substack{x=a/2 \\ y=0}} = -\gamma \frac{P}{a} \quad . \quad . \quad (15)$$

in which the negative sign denotes an upward shear at this point.

The total vertical reactions along the edges are given by

$$R_x = \int_{-b/2}^{b/2} (Q_x)_{x=a/2}\, dy = -\delta_x P \quad . \quad . \quad . \quad . \quad . \quad (16)$$

$$R_y = \int_{-a/2}^{a/2} (Q_y)_{y=b/2}\, dx = -\delta_y P \quad . \quad . \quad . \quad . \quad (17)$$

TABLE 1.

SYSTEM OF EQUATIONS (11).

$$
\begin{aligned}
1.1210\,A_1 + 0.73912\,B_1 &+ 0.12112\,B_3 + 0.03147\,B_5 + 0.01211\,B_7 + 0.00583\,B_9 + \ldots &&= -0.17066\,P\\
0.3334\,A_3 + 0.06774\,B_1 &+ 0.08213\,B_3 + 0.04581\,B_5 + 0.02407\,B_7 + 0.01346\,B_9 + \ldots &&= \;\;0.001400\,P\\
0.2000\,A_5 + 0.01607\,B_1 &+ 0.03260\,B_3 + 0.02957\,B_5 + 0.02132\,B_7 + 0.01447\,B_9 + \ldots &&= -0.0000194\,P\\
0.1429\,A_7 + 0.00602\,B_1 &+ 0.01460\,B_3 + 0.01687\,B_5 + 0.01509\,B_7 + 0.01207\,B_9 + \ldots &&= \;\;0.00000032\,P\\
0.1111\,A_9 + 0.00286\,B_1 &+ 0.00753\,B_3 + 0.00987\,B_5 + 0.01010\,B_7 + 0.00912\,B_9 + \ldots &&= \;\;0
\end{aligned}
$$

TABLE 2.

SYSTEM OF EQUATIONS (12).

$$
\begin{aligned}
1.1958\,B_1 + 0.51331\,A_1 &+ 0.04704\,A_3 + 0.01116\,A_5 + 0.00418\,A_7 + 0.00199\,A_9 + \ldots &&= -0.18125\,P\\
0.3351\,B_3 + 0.08411\,A_1 &+ 0.05703\,A_3 + 0.02264\,A_5 + 0.01014\,A_7 + 0.00523\,A_9 + \ldots &&= \;\;0.005467\,P\\
0.2000\,B_5 + 0.02186\,A_1 &+ 0.03181\,A_3 + 0.02054\,A_5 + 0.01171\,A_7 + 0.00685\,A_9 + \ldots &&= -0.000239\,P\\
0.1429\,B_7 + 0.00841\,A_1 &+ 0.01672\,A_3 + 0.01481\,A_5 + 0.01048\,A_7 + 0.00702\,A_9 + \ldots &&= \;\;0.0000125\,P\\
0.1111\,B_9 + 0.00405\,A_1 &+ 0.00934\,A_3 + 0.01005\,A_5 + 0.00838\,A_7 + 0.00634\,A_9 + \ldots &&= -0.00000071\,P
\end{aligned}
$$

TABLE 3.

VALUES OF A_m AND B_m FOR VARIOUS RATIOS b/a.

b/a	1.0	1.2	1.4	1.6	1.8	2.0
A_1	$-0.1025\,P$	$-0.0764\,P$	$-0.0524\,P$	$-0.0339\,P$	$-0.0206\,P$	$-0.0118\,P$
A_3	$0.0263\,P$	$0.0200\,P$	$0.0145\,P$	$0.0099\,P$	$0.0065\,P$	$0.0040\,P$
A_5	$0.0042\,P$	$0.0036\,P$	$0.0026\,P$	$0.0016\,P$	$0.00099\,P$	$0.00049\,P$
A_7	$0.0015\,P$	$0.0011\,P$	$0.00075\,P$	$0.00044\,P$	$0.00025\,P$	$0.000080\,P$
A_9	$0.00055\,P$	$0.00040\,P$	$0.00025\,P$	$0.00014\,P$	$0.00007\,P$	$0.000003\,P$
A_{11}	$0.00021\,P$					$-0.000017\,P$
A_{13}	$0.00006\,P$					$-0.000028\,P$
B_1	$-0.1025\,P$	$-0.1196\,P$	$-0.1246\,P$	$-0.1224\,P$	$-0.1168\,P$	$-0.1100\,P$
B_3	$0.0263\,P$	$0.0318\,P$	$0.0360\,P$	$0.0397\,P$	$0.0431\,P$	$0.0461\,P$
B_5	$0.0042\,P$	$0.0035\,P$	$0.0014\,P$	$-0.0015\,P$	$-0.0049\,P$	$-0.0083\,P$
B_7	$0.0015\,P$	$0.0018\,P$	$0.0018\,P$	$0.0019\,P$	$0.0021\,P$	$0.0027\,P$
B_9	$0.00055\,P$	$0.00066\,P$	$0.00061\,P$	$0.00045\,P$	$0.00019\,P$	$-0.00014\,P$
B_{11}	$0.00021\,P$					$0.00023\,P$
B_{13}	$0.00006\,P$					$0.00004\,P$

The values of the coefficients α, β, γ, δ_x, δ_y in Equations (13) to (17) were calculated and are given in Table 4 and Figs. 2 and 3. In the calculations for the coefficient α, the value of Poisson's ratio has been taken as $\mu=0.3$.

TABLE 4.

VALUES OF DEFLECTION, MOMENT, SHEAR, AND REACTION COEFFICIENTS AS DEFINED IN EQUATIONS (13) TO (17).

b/a	α	β	γ	δ_x	δ_y
1.0	0.0611	0.1257	0.794	0.250	0.250
1.2	0.0706	0.1490	0.877	0.347	0.153
1.4	0.0755	0.1604	0.908	0.417	0.083
1.6	0.0777	0.1651	0.916	0.459	0.041
1.8	0.0786	0.1667	0.918	0.484	0.016
2.0	0.0788	0.1674	0.919	0.498	0.002

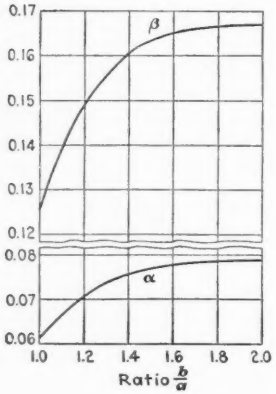

FIG. 2

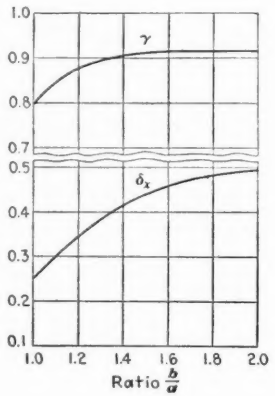

FIG. 3

ACKNOWLEDGMENT.

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ABSTRACTS FROM THE SCIENTIFIC AND TECHNICAL PRESS.

Issued by the
Directorates of Scientific Research and Technical Development, Air Ministry.
(Prepared by R.T.P.)

No. 76. March, 1940.

Mystery of the Magnetic Mine. (C. E. Milbury, Scientific American, Vol. 162, No. 3, March, 1940, pp. 156-7.) (76/1 U.S.A.)

Magnetic mines are of two types, the inert or shallow water type and the mobile or deep water type. Both types can be dropped into the sea from a height of 200 feet without a parachute, the detonator not becoming alive until the mine has been submerged for some time. The shallow water mine is laid in waters approximately 50 feet deep, whilst the deep water type will operate at depths up to 400 feet. Both types of mines normally rest on the bottom of the sea, and since neither cables nor anchors are required, the weight of the mine is not great and a medium size aircraft may carry a dozen or more.

The article describes, in very general terms, the magnetic relay which is effected by a ship passing in close proximity. In the case of the inert or shallow mine, the explosive is fired when the ship is immediately overhead. In the case of the mobile mine, the relay begins to operate with the ship at some distance. The first action of the relay is to cause the mine to rise by expelling water ballast by means of compressed air. When the mine has reached a depth of about 50 feet, the charge is fired. In each case the resultant pressure wave is liable to seriously injure the ship's bottom. The new type of mine thus does not operate by contact, but resembles rather a depth charge.

According to the author, the sweeping up of such mines will present considerable difficulties. Perhaps the best method of destroying such mines will be by dropping barrages of small depth charges from aircraft over suspected waterways.

Army Co-operation with Fixed and Rotary Wing Aircraft. (R. Maurer, La Science et La Vie, Vol. 57, No. 273, March, 1940, pp. 166-78.) (76/2 France.)

The term army co-operation is restricted by the author to short-range reconnaissance over objectives of the land armies, covering a region roughly corresponding to the zone of operation of the various corps. Since enemy territory need only be observed to a relatively small depth (10-15 km.), use of a light, cheap and unarmed aircraft has been proposed by some authorities. The low speed of such a machine would facilitate observation at altitude and landing on rough ground, while the low cost would favour employment of large numbers and facilitate training of observers. However, in practice, reconnaissance over land army objectives has to be carried out from relatively low altitudes, and the low-speed light observation plane then becomes an easy prey to enemy raiding fighters.

A special design combining a certain amount of armament with an excellent field of view and a large speed range is therefore required. Moreover, a reason-

able top speed performance is necessary and the machine must be a two or three-seater. Some of the characteristics of co-operation machines evolved by different countries are described (Westland Lysander, North American 047A, Caproni CA 134, Hanriot 510).

German types are the Henschel Hs 126 and the Fieseler Storch, the latter having the exceptional speed range of 4/1. Its top speed is rather low (130 m.p.h.), but it is, nevertheless, regarded by the author as the best solution of the problem so far. In theory the autogiro should provide an ideal observation machine, but it is practically defenceless against attacks from above and thus its field of application is very limited.

Determination of the Coefficient of Friction of Steel Rubbing on Steel at High Velocities. (G. Grotsch and E. Plake, Z.G.S.S., Vol. 35, No. 1, pp. 3-5, and No. 2, pp. 30-32.) (76/3 Germany.)

Experiments were carried out by the authors on smooth steel cylinders which were fired in smooth (unrifled) barrels at muzzle speeds varying between 100 and 700 m./sec.

The projectiles were of equal weight (5.3 gm.) and calibre (7.9 mm.), but differed in shape, one of them being solid whilst the other had the rear portion hollowed out, thus producing the equivalent of a thin-walled piston. The friction of the solid head is assumed to be the same as that of the undrilled cylinder. The difference in the friction of the two projectiles in the barrel is thus due to the piston walls being pressed outwards on to the barrel. By measuring the difference in muzzle velocity of the two projectiles for different explosive charges (gas pressures), values for the coefficient of friction can be deduced for a series of mean speeds in the barrel. It appears that the coefficient of friction, which under static conditions is of the order of 0.27 for steel on steel, undergoes a marked reduction with increase in rubbing speed. This is shown in the following table:—

V (rubbing m./sec. speed).	μ
0	0.27
100	0.05
500	0.03
1000	0.02
∞ (extrapolated)	0.019

These results can be explained by the fact that at high rubbing speeds there is insufficient time for the boundary layer to be destroyed, and interlocking of the surface molecules is considerably restricted. It is well known that the static friction of copper on steel is smaller than that of steel on steel and preliminary experiments with the same projectiles, but copper plated, have shown that the skirted cylinder has practically the same muzzle velocity as the solid projectile.

If the reduction of friction with speed shown in the above experiments is accepted, calculations on the spin of projectiles carried out with the static coefficient are in error, and new design possibilities arise.

The Transition from Subsonic to Supersonic Velocity in a Gas Flowing Through a Nozzle. (H. Gortler, Z.A.M.M., Vol. 19, No. 6, Dec., 1939, pp. 325-337.) (76/4 Germany.)

The mathematical methods employed for the investigation of a purely subsonic or supersonic flow give no information on mixed problems, where there is a transition from subsonic to supersonic or vice-versa. In this case the fundamental differential equation for the stream function changes from the elliptic to the hyperbolic type and the mathematical difficulties of the problem increase considerably. In the case of two dimensional flow, Th. Meyer gave a possible solution with a discontinuity stretching right across the throat of the nozzle (V.D.I. Research Paper, No. 62, 1908). A symmetrical solution, in which the

discontinuities are confined to two small regions in the neighbourhood of the throat was given later by G. I. Taylor in 1930 (R. and M. 1381). The author investigates possible analytical transitions from the symmetrical Taylor type to the unsymmetrical case treated by Meyer. It appears that such an analytical transition is only possible in the immediate neighbourhood of the axis and that in general shock waves must arise.

Construction of Wing Polars, Taking into Account Variation in Reynolds Number with Angle of Incidence and Altitude. (A. S. Kravets, Aeron. Eng., U.S.S.R., Vol. 13, No. 11, Nov., 1939, pp. 9-21.) (76/5 U.S.S.R.)

This investigation shows that in order to obtain more accurate flight data, aerodynamic calculations should be carried out on the basis of wing polars which have been corrected for the effect of variation in Re over all ranges of incidence and altitude.

For purposes of practical computation the following assumptions may be made:—

(*a*) The wing polar diagram is calculated for a mean altitude and correction is only made for variation in Cy value.

(*b*) When passing from the wind tunnel polar to actual flight conditions it is sufficient to recalculate the corresponding point of maximum velocity and to plot the flight polar at constant distance from the experimental curve displacement. The error for an atmospheric wind tunnel at $Cy < 0.45$ will be less than 6 per cent. of the profile drag. For a variable density wind tunnel the corresponding error will be of the order of 11 per cent. When $Cy > 0.5$ the value of the error in profile drag increases, but not very greatly.

Use of these assumptions can considerably simplify calculation.

The methods given in this paper for the construction of full-scale wing polars can also be employed for estimating the effect of variation in Re on friction drag.

Thermo-Convective Vortices in Air. Their Application to Meteorology. (D. Avsec, Pub. Sci. et Tech., No. 155, 1939, 214 pp.) (76/6 France.)

The present paper describes a study of thermo-convective vortices in a layer of air uniformly heated from below.

CONTENTS.

I.—Historical survey of general studies of convection.

II.—Vertical instability in layers of fluid and the inception of systemmatic movements.

III.—Description of the apparatus employed for production of thermo-convective vortices in a horizontal layer of air. Mode of operation.

IV.—Thermo-convective vortices in a stationary layer of air or one undergoing translatory motion; principal types and the mechanism of their development.

V.—Transformations between the main types. Intermediate forms of thermo-convective vortices.

VI.—Résumé of the theory of thermo-convective vortices.

VII.—Determination of the Rayleigh-Bénard criterion in certain particular cases.

VIII.—Dimensions of thermo-convective vortices.

IX.—Variation of the ratio λ/h for vortices in longitudinal bands, and their stability.

X.—Lines of flow.

XI.—Temperature distribution in a fluid layer containing cellular vortices.

XII.—Application of the theory of thermo-convective vortices to meteorology.

The Forces on a Plane Aerofoil in a Wind Tunnel of the Goettingen Type, with Special Reference to the Approximate Formula for the Lift. (S. Tomotika and H. Umemoto, Aer. Res. Inst., Tokio, No. 185, Nov., 1939.) (76/7 Japan.)

The paper is of interest in giving the full steps of the calculation by the method of conformal representation of the forces acting on flat plane of chord (width) $2a$ placed in a two dimensional jet of width D at infinity. If U = velocity at infinity, the lift L is given by the equation $L = \rho U^2 D \sin \alpha$, when α = deviation of jet at $-\infty$. (This result, of course, can also be obtained directly from the impulse theorem.) In the case of an unlimited stream, $L_0 = 2\pi a U^2 \rho \sin \beta$ where β = inclination of plate with x axis. We thus have

$$L/L_0 = (D/2\pi a)(\sin \alpha / \sin \beta).$$

It is thus possible to express L/L_0 as a function of $2a/D$ once the relationship between α and β is determined. It is found that the interference effects of the free boundaries of a finite jet cause a reduction in the lift for values of β between 5° and 15°, the effect being the greater the larger $2a/D$.

The effect of change in β over the range investigated is small and may be neglected if $2a/D < 0.2$, which is the usual case.

The authors deduce an approximate formula for L/L_0 as a function of $(2a/D)$ and β which, if $\beta = 0$ reduces to the well known equations of Glauert and Pistolesi (to the second order $2a/D$).

Mathematical Theory of Irrotational Translation Waves. (G. H. Keulegan and G. W. Patterson, Bur. Stan. J. Res., Vol. 24, No. 1, Jan., 1940, pp. 47-101.) (76/8 U.S.A.)

This paper is the first of a series dealing with the motion of flood waves and other waves of translation in open channels. The case treated is that of waves for which the forces of fluid friction are negligible with respect to the inertia and gravitational forces. The irrotational motion of a perfect liquid in a horizontal rectangular canal when the original surface is disturbed is investigated on the assumption that the horizontal velocity in a cross section is approximately uniform. The results are also applicable to motion in a canal of uniform slope containing water originally moving with a uniform velocity. Special emphasis is laid on disturbances which are propagated without change of form, and in these cases formulas are derived for the wave profile and velocity of propagation. Consideration is given to the maximum height of a wave of permanent form. Formulas have been compared with the available experimental data. Of special interest is the comparison of the shape of the undulations composing the head of an initial surge with the characteristics of the cnoidal wave.

Model Experiments in Flow-Channels Using Various Media. (W. Bardili, Phys. Zeit., Vol. 41, Nos. 3-4, 15/2/40, pp. 63-76.) (76/9 Germany.)

On the basis of the theory of similarity a calculation is made of the media which will require a small velocity of flow in order to obtain given values of Mach's and Reynolds numbers. In addition it is shown how the relative loss of flow channels (*e.g.*, with respect to air) can be calculated for various media, assuming that the same Reynolds or Mach's number, or even the same velocity, is to be reached. It was found that in order to reach a high Reynolds number with small losses the following relationship must hold:—

$$\mu^{*3}/\rho^{*2} = \mu\nu^2;$$

i.e., the product of viscosity and the square of the kinematic viscosity must be as small as possible. Thus, mercury and ether give approximately 100 per cent. smaller losses than air. The losses occurring on obtaining a given value of Mach's number, without taking into account any impulse losses, are approximately proportional to

$$(\mu^{*0.2})/(\rho^{*0.6} \cdot k^{*1.4}).$$

Therefore in this case heavy gases or vapours (ρ) of large compressibility (k) and small friction value (μ) are most suitable. For example, the losses obtained with iso-propane are half as great as with air. Finally, the lengths of channel, referred to air, required in order to reach a given Reynolds or Mach's number with equal loss are calculated.

Stability and Configuration of the Wakes Produced by Solid Bodies Moving Through Fluids. (S. H. Hollingdale, Phil. Mag., Vol. 29, No. 194, March, 1940, pp. 209-257.) (76/10 Great Britain.)

PART I.

The stability of certain types of "one-dimensional" steady flow in an unlimited viscous fluid has been investigated by the method of "small oscillations." The general result is obtained that the velocity of the oscillations (in the direction of motion of the main flow) is equal to the velocity of the main flow at the point of inflexion of the laminar velocity profile.

Two profiles of physical interest are considered in greater detail and approximate values obtained for the wave-length of the oscillations.

PART II.

Photographs have been obtained of the wakes produced by models (flat plates and symmetrical aerofoil sections at zero incidence) moving in a tank of water. Oscillations do not occur when the Reynolds number is less than 600 for the flat plate and 1,000 for the aerofoil section, and it is probable that the onset of instability can be considerably delayed by careful elimination of all "residual motions" of the water.

The velocity field in the laminar wake has been measured, and a comparison made with certain results of Goldstein and Fage. Good agreement is obtained, the divergence being appreciable at the edges of the wake due to the effect of the walls of the tank.

Measurements of the wave-length and wave-velocity have been made for various oscillating wakes, for a comparison with the conclusions of Part I. The agreement between theory and experiment is, on the whole, satisfactory, but the comparison is somewhat blunted owing to several difficulties in the interpretation of the theoretical results.

Some Aspects of Aero-Hangar Design. (A. M. Hamilton and E. B. Cocks, J. Inst. Civ. Engs., Vol. 13, No. 4, Feb., 1940, pp. 305-336.) (76/11 Great Britain.)

(1) In exposed aero-hangars, the wind pressure on the windward side is normally of less intensity than the wind suction on the roof, which has its highest values on the windward slope near the eaves, and diminishes towards the leeward eaves, with no sudden change at the ridge. There is normally no positive pressure on the roof.

(2) In designing a large aero-hangar, it is advisable to obtain a wind tunnel test report giving the pressure distribution.

(3) The tunnel tests indicate the wind forces on a closed-in structure, and they also give the values of the air pressures or suctions, which the covering of the shed, including windows and doors, should be able to resist in a wind of specified velocity. The tests indicate also the "emergency" pressures on the building structure should there be any opening in the covering.

(4) When a high wind blows through an open doorway or window into any closed building there is always a considerable uplift effect on the roof. Therefore, even in normal roof trusses of ordinary span and pitch the truss members should be capable of withstanding reversal of stress. The roof covering should always be adequately secured against uplift forces, and the hangar itself adequately anchored down.

(5) Winds from any direction lessen the dead load stresses except when there is a hole in the roof.

(6) The most stable form of light building construction is the lattice rib of as wide a box section as convenient; the cross section should be constant right to the foundation bases.

(7) The maximum bending moment in the rib for "hinged ends" is of the same order as that for "fixed ends."

(8) The roof ribs, as designed for an 80-mile per hour wind with a factor of safety of $1\frac{1}{2}$, are found to be adequate for small snow loads.

(9) For countries where the snow load may vary from 15 to 36 lb. per square foot, the ribs need be designed against this vertical loading only, and if continuous and capable of taking full reversals of stress, they will then be adequate for any wind.

(10) The box lattice rib has advantages, for service conditions which require stability under bombing and ease of repair if damaged, and also in its capacity as a girder to take reversals of stress due to wind uplift. Single girder ribs or simple roof trusses are not usually so well able to carry compression in the lower tie or chord.

Pressure-Distribution Measurements on a Rectangular Wing with a Partial Span Split Flap in Curved Flight. (F. G. Rokus, N.A.C.A. Tech. Note, No. 742, Dec., 1939.) (76/12 U.S.A.)

Pressure-distribution tests were made on the 32-foot whirling arm of the Daniel Guggenheim Airship Institute of a rectangular wing of N.A.C.A. 23012 section to determine the rolling and the yawing moment due to an angular velocity in yaw. The model was tested at 0° and 5° pitch; 0°, $\pm 5°$, and $\pm 10°$ yaw; and with no flap and with split flaps 25, 50 and 75 per cent. of the wing span and deflected 60°.

CONCLUSIONS.

1. The experimental rolling moment and yawing moment coefficients are in fairly close agreement with theoretical values.

2. The rolling moment coefficients are little affected by the angle of yaw within the range tested of $\pm 10°$.

3. Small variations in the normal force distribution, especially at the tips of the wing, have little effect on the resulting rolling moment coefficient.

4. The yawing moment coefficients exhibit considerable change due to the angle of yaw, especially on the model with a partial span flap. The coefficient increases as the wing model is yawed in a positive direction, and decreases as the wing model is yawed in the negative direction. The yawing moment coefficient for $-10°$ yaw reaches a slight negative value for the 25 per cent. and the 50 per cent. span flaps, the trend of the curves indicating larger negative coefficients for yaw angles beyond $-10°$.

5. The negative yawing moments for 25 per cent. and 50 per cent. span flaps at $-10°$ yaw angle are brought about, as is apparent from pressure distribution curves, by the somewhat higher pressure on the forward side of the flap near its tip on the inner portion of the span as compared with the outer portion, accompanied by a somewhat higher negative pressure at the rear of the flap on the inner portion of the span as against the outer portion.

Relative Performance with 87 and 100 Octane Fuel on Koolhoven Fk. 59 Two-Seater Reconnaissance Bomber (Mercury XV) Engine. (Flight, Vol. 37, No. 1626, 22/2/40, p. 180.) (76/13 Holland.)

The following comparative figures for the performance of the Koolhoven Fk 59 two-seater reconnaissance bomber biplane with Bristol Mercury XV engine show the advantages in performance arising from the use of 87 octane and 100 octane fuels.

	87 Octane.	100 Octane.
Maximum speed at 2,750 r.p.m.	236 m.p.h.	260 m.p.h.
Height for maximum speed	15,700 ft.	17,300 ft.
Cruising speed at 60 per cent. maximum power	192 m.p.h.	211 m.p.h.
At height of	15,700 ft.	17,300 ft.
Rate of climb at sea level	1,490 ft./min.	2,180 ft./min.
Rate of climb at 6,500 ft.	1,630 ft./min.	2,360 ft./min.
Rate of climb at 13,000 ft.	1,730 ft./min.	2,540 ft./min.
Rate of climb at 19,500 ft.	1,220 ft./min.	2,050 ft./min.
Time of climb to 6,500 ft.	4.2 min.	2.9 min.
Time of climb to 13,000 ft.	8.0 min.	5.6 min.
Time of climb to 19,500 ft.	12.3 min.	8.3 min.
Time of climb to 26,000 ft.	19.4 min.	12.2 min.
Service ceiling	31,800 ft.	35,700 ft.
Absolute ceiling	32,800 ft.	36,700 ft.
Range with 837 lb. fuel at cruising speed ...	621 miles	540 miles
At height of	15,700 ft.	17,350 ft.

The performance of the engine itself is also interesting:—

	87 Octane.	100 Octane.
Maximum output	830 h.p.	1,050 h.p.
Maximum power height	14,450 ft.	15,580 ft.
Maximum r.p.m.	2,750	2,750
Fuel consumption at cruising speed	242.5 lb./h.	308.5 lb./h.

Tests of a Gust-Alleviating Flap in the Gust Tunnel. (P. Donely and C. C. Shufflebarger, N.A.C.A. Tech. Note No. 745, Jan., 1940.) (76/14 U.S.A.)

Tests were made in the N.A.C.A. gust tunnel to determine the effectiveness of a long period dynamically overbalanced flap in reducing aeroplane accelerations due to atmospheric gusts. For two gust shapes, one gust velocity, one forward velocity, and one wing loading, a series of flights was made with the flap locked and was then repeated with the flap free to operate. The records obtained were evaluated by routine methods.

The results indicate that the flap reduced the maximum acceleration increment by 39 per cent. for a severe gust with a representative gust gradient distance of 8 chord lengths and that, for an extreme gust shape (a sharp-edge gust), the reduction was only 3 per cent. The results also indicate that the flap tended to reduce the longitudinal stability of the aeroplane. Computations made of the effectiveness and the action of the flap were in good agreement with the experimental results.

The Frequencies of Cantilever Wings in Beam and Torsional Vibrations. (C. P. Burgess, N.A.C.A. Tech. Note No. 746, Jan., 1940.) (76/15 U.S.A.)

Methods are described for calculating the period and frequency of vibration of cantilever wings and similar structures in which the weight and moment of inertia vary along the span. Both the beam and torsional frequencies may be calculated by these methods. The procedure is illustrated by examples.

It is shown that a surprisingly close approximation to the beam frequency may be obtained by a very brief calculation in which the curvature of the wing in vibration is assumed to be constant. A somewhat longer computation permits taking account of the true curvature of the beam by a series of successive approximations which are shown to be strongly convergent.

Analogous methods are applied to calculations of the torsional frequency. For the first approximation it is assumed that the angle of twist varies linearly along the semi-span. The true variation of the twist is computed by successive approximations which are strongly convergent, as in the case of beam vibrations.

Air Forces on Radial Air-Cooled Engine Cowling as Determined from Pressure Distribution Tests. (R. R. Higginbotham, Paper to S.A.E. Annual Meeting, 15-19/12/39. Available in R.T.P.) (76/16 U.S.A.)

Factors influencing engine cowl surface pressures are considered, and the results of pressure tests on one cowl model in the wind tunnel and on three representative cowl designs in flight are analysed. Some of the preliminary conclusions are as follows:—

1. Where the external airflow is essentially non-turbulent and the local velocities are below the speed of sound, and where the conductivity of the engine baffle combination is independent of air speed, the aerodynamic forces on an engine cowl without propeller are proportional to the dynamic pressure of the free air stream.

2. Where the local velocities in the external airflow exceed the speed of sound, the relation between air speed and surface pressures is not definitely known, but it is likely that the air loads are less severe above the critical speed.

3. Tests on R-1535 and " Wasp " engine cowls indicate that the aerodynamic forces are higher with power off than with power on.

4. For a given cowl the largest forces occur at the lowest conductivity of the engine baffle combination.

5. At positive angles of incidence of the thrust axis the unsymmetrical pressure distribution results in increase in aerodynamic load on the upper half of the cowl and decrease on the lower half, giving rise to an upward translational force and a pitching couple.

6. At positive angles of incidence, the combination of yaw at the horizontal sections and slipstream twist may also produce a lateral translational force and a horizontal couple.

7. The most severe cowl forces occur at the largest angle of incidence obtainable at maximum velocity.

Correlation of Wind Tunnel and Flight Test Results. (W. W. Symington, Paper to S.A.E. Annual Meeting, 15-19/12/39. Available in R.T.P.) (76/17 U.S.A.)

Accurate co-ordination of wind tunnel test results and results obtained in actual flight is the only available method for accurately predicting the performance of a new aircraft design. Wind tunnel results do not fully determine the actual performance in free flight, other variables which have to be considered are the Reynolds number, turbulence, surface conditions, slipstream, propeller, engine power and engine cooling drag. In general these factors, with the wind tunnel results, can be combined into three separate major variables, *i.e.*, engine power, propeller and drag. The engine power and propeller efficiency are important as a means of measuring flight test drag. Any one of these three variables may be adjusted after a flight test to arrive at the correct result. The real problem, however, is to predict the performance, and this can only be done correctly if the power, propeller efficiency and drag used in the calculations are the same as the corresponding values in the flight test after the plane has been built.

Aluminium Aircraft Fuel Tanks. (E. H. Dix and R. B. Mears, Paper to S.A.E. Annual Meeting, 15-19/12/39. Available in R.T.P.) (76/18 U.S.A.)

Aluminium fuel tanks, in use for many years, have generally given entirely satisfactory results. In isolated cases, however, pitting by corrosion has occurred, usually due to water contaminated with chlorides, bromides and heavy metal compounds lying in the bottom of the tank for a considerable time.

Corrosion is prevented by:—Suitable design to permit free drainage; selecting metals to avoid electrolytic action; preventing contamination of the fuel by water, rust or other heavy metal corrosion products prior to its entry into the fuel tank; applying protective coatings to the interior of the tank, such as an anodised layer,

subsequently impregnated with potassium bichromate, or by use of protective paints; use of corrosion inhibitors either in capsules inserted in the tanks or as an addition to the fuel; periodic cleaning of the tank interiors or flushing them with inhibited solutions.

Future Possibilities of the Autogiro (Civil and Military). (G. Favier, La Science et la Vie, Vol. 57, No. 273, March, 1940, pp. 179-186.) (76/19 France.)

The original Cierva autogiro was unmanageable on the ground, both during take-off and landing, due both to the high C.G. position and the gyroscopic couple of the rotor. In addition, any gust striking the machine during take-off run sets up violent rotor blade oscillations. Directional control on the ground is mainly by the tail wheel and it is thus essential that this wheel leaves the ground last during take-off and touches it first during landing. Even after touching the ground at low speed, the continued rotation of the rotor causes considerable lift and on the wind freshening the machine may rise again and very likely come to grief. These difficulties have now been overcome by providing a rotor blade incidence control mechanism, either automatic or under pilot control. It is possible both to land and take-off without any run on the ground, and since the blade incidence can be changed to give no lift, the machine is rendered much less sensitive to gust. Finally, a flap on the trailing edge of the rotor blade eliminates any danger of the blade incidence decreasing excessively during a steep dive and the autogiro is thus rendered automatically stable. (Lateral stability of the fuselage is assured by suitable arrangement of the tail surface.) By these two improvements the autogiro has been rendered safe both in the air and on the ground, and a great future is predicted for it. In civil aviation an obvious application will be as feeder aircraft between towns and outside aerodromes. In war, there are also a number of possible applications provided the machine is not exposed to actual air fighting. In the U.S.A., extensive use is being made of autogiros to replace observation balloons for artillery range finding. In these cases the autogiro can keep in telephonic communication with the ground by means of a cable, the tension of which is kept constant by means of an automatic winding drum.

Review of Some Messerschmitt Aircraft Patents (French and German). (L'Aéronautique, Vol. 22, No. 248, January, 1940, pp. 19-21.) (76/20 France.)

French Patent No. 779936.—Prevention of spin by a progressive thickening and rounding off of the wing nose, along the span, the central wing section having a pointed nose. As an alternative, the wing section is of normal shape along the span, but provided over the central section with a spoiler placed at the stagnation point.

French Patents 841781, 841976.—Boundary layer control by suction, an interconnection (channel) inside the wing providing a direct means of pressure equalisation between regions of low and high pressure respectively.

French Patent 808710.—Metallic fuselage without independent transverse frame members, the latter being formed by the sheet metal at one end of the cylindrical sections being turned inwards to form a circumferential lip or flange whilst the other end of the section is left unaltered. The fuselage is built up by riveting the plain ends on to the flanges, the latter being provided with cut outs for the wing spars.

German Patent 672053.—Wing fuselage attachment for low wing aircraft characterised by the fact that the compression forces at the foot of the wing spar are transmitted to a pyramidal structure, and are taken up partly by the fuselage spars and partly by frame members passing through the fuselage well to the rear of the wing span and connecting up with the other wing. The central section of the fuselage is thus kept quite clear. The same principle can also be applied to multi-spar wings.

French Patent 780664.—Lateral control for aircraft by means of wing spoilers placed near the tips, the deflection of which increases progressively along the span. This can be arranged either by sub-dividing the spoiler into sections which are deflected in succession, or the spoiler itself may be of a warped or twisted shape so as to produce the effect of variable incidence. The spoilers, working in a region of depression on the upper wing surface, have the tendency to open, and by providing suitable spring control, the action can be rendered automatic and excessive wing strain during a pull-out avoided.

French Patent 829768.—Ammunition feed for aircraft machine guns in the form of endless belts stored inside the wing.

Speed Control Device for the Propellers of a Twin-Propeller Aircraft. (Siemens-Schuckertwerke A.G.; D.R.P. 683,062, 30/10/39. Flugsport, Vol. 32, No. 2, 17/1/40, p. 79.) (76/21 Germany.)

1. Control for an aircraft power plant consisting of at least two propellers, preferably driven from a common motor having counter-rotating parts, characterised by the fact that the driving shaft of each propeller, in addition to being connected to the actual motor, is also connected to an electric motor; the latter connection is such that the electric motor can serve either as a generator, for the purpose of reducing the speed of rotation of the appropriate shaft, or as a motor for the purpose of increasing it.

2. Drive as in claim 1, in which the shaft of each propeller is coupled to the rotor of a direct current motor, the two rotors are connected in series, and the excitation of these direct current motors can be adjusted by a governor so that the one motor acts as a generator and the other as a motor, as required.

3. Drive as claimed in 1 and 2, in which the common driving motor is a three-phase current motor.

Some New Investigations on Old Combustion Engine Problems (I). (G. Eichelberg, Engineering, Vol. 148, No. 3850, 27/10/39, pp. 463-466.) (76/22 Switzerland.)

In this first lecture, the author deals with the problem of heat transfer in engine cylinders. The experiments were carried out on large Diesel engines varying in bore from 280 to 600 mm. The heat transfer coefficient a (kilo calories/M^2/hour/°C.) between the metal and the cooling fluid is easily obtained from the known heat loss and the temperature difference between the surface and the fluid. The value of a increases with the rate of flow of the cooling fluid, the following being representative values:—

	Rate of flow (Kg./M^2/hour).			
a	2,000	5,000	10,000	25,000
Cylinder head	—	1,000	—	2,500
Liner	500	1,000	—	—
Piston (oil-cooled) ...	—	300	1,200	—

In the case of the heat transfer from the working medium (gas), to the walls, the heat transfer coefficient is found to vary very markedly during the cycle. The heat entering the surface at any instant is equal to

$$\lambda \, (\partial T/\partial x)_{x=0}$$

and this must be equal to $a\,(\theta - T)$, where

a = heat transfer coefficient between gas and wall.

θ = gas temperature at same instant.

T = wall surface temperature at same instant.

Assuming θ to be given by the indicator diagram, and

$$(\partial T/\partial x)_{x=0}$$

to be determined experimentally, a can then be calculated. The following mean values (time basis) for a were obtained for the piston crown of a two-stroke engine at 300 r.p.m.:—

a mean (Full load) = 300 kilo. cal./M^2/h./°C.
(Half load) = 250 ,, ,,
(Motoring) = 200 ,, ,,

Wear of Diesel Engine Cylinders and Rings (with Discussion). (P. S. Lane, Trans. A.S.M.E., Vol. 62, No. 2, Feb., 1940, pp. 95-110.) (76/23 U.S.A.)

This paper considers wear mainly from the viewpoint of cylinder and ring materials, rather than from the design or operating angle. The types of iron used, though important factors, have received only limited attention in published data. Existing wear rates in medium and heavy duty Diesel and gas engines in various fields of service are reviewed, followed by several examples of cylinder wear as affected by the hardness and structure of the iron alloy. By means of laboratory wear tests, correlated with service experience, the nature and characteristics of the materials used in cylinders and rings are surveyed and discussed in detail, covering the effects of section size, hardness, analysis and structure. Initial engine wear, as influenced by bore finishes and wear-resistant or chemical surface treatments, is considered, together with the action of bi-metallic or composite rings, in retarding scuffing and overall wear rates. It is the author's opinion, which seems to be substantiated by the work reported in this paper, that in some cases a possible reduction in wear rates of 2 to 1 may be expected through proper balance of ring and cylinder structures. There is further evidence that with existing conditions, a reduction in cylinder wear of roughly 2 to 1 may be obtained through the use of bi-metallic and/or chemically treated rings. Thus, theoretically at least, there appear to be possibilities for an overall decrease in wear rates in the order of 4 to 1; that is, wear seems possible of reduction to one-fourth of existing averages. The *rôle* of corrosion in cylinder wear is not considered important.

Shortcomings of Mica as an Insulating Material in Aviation Spark Plugs. (V. Cronstedt, Paper at S.A.E. Annual Meeting, 15-19/1/1940.) (76/24 U.S.A.)

Between 80 and 90 per cent. of delays in American air transport are due to ignition troubles, and although these are not all due to spark plugs, maintenance records selected at random show a figure of 2,187 unscheduled plug replacements in about 60 engines during 5,350 flying hours. One disadvantage of mica as a spark plug insulator is its low heat conductivity, as a result of which a plug may become so cold under idling conditions that oil, petrol, moisture and deposits accumulate under the insulator and short-circuit the plug. Under full load the plug may become so hot that its materials are destroyed. At 1,000-1,200°F., mica is dehydrated, resulting in rapid deterioration of the plug. In order to reduce the maximum temperature of the nose of the central electrode, manufacturers have reduced the thickness of the mica tube to facilitate heat flow. This, however, leads to fragility and increases the electrical capacity of the secondary circuit. The thermal expansion of mica is less than half that of the central electrode (stainless steel), which tends to loosen the washers at high temperatures and enables carbon, oil, etc., to lodge between them.

Mica is liable to react with lead oxide formed by oxidation of the deposit formed on the exposed plug surface during combustion of leaded fuels. Any deposits of lead silicate formed in this way greatly change the thermal properties of the plug.

New Measurements on Diesel Engines and Their Effect on Development. (C Zublin, W.R.H., Vol. 21, No. 4, 15/2/40, pp. 45-47.) (76/25 Switzerland.)

Experiments carried out on a single cylinder Sulzer two-stroke Diesel engine of 720 mm. bore and 1,250 mm. stroke comprised:—Temperature measurements over the cylinder head, piston and liner under various conditions of load; investiga-

tions of the deflection of the piston crown under loads and the distribution of gas pressure behind the piston rings; stress measurements on various parts of the engine frame under static loads (compressed air) and the deflection of the cylinder head under actual power conditions. Fuel characteristics were also investigated and it was found that the main effect on engine operation of a change in fuel occurred during light load. Indicator diagrams taken under such conditions are recommended as a ready means of classifying fuel oils.

The other main conclusions are:—

(1) At constant r.p.m. and scavenge, the engine temperatures rise rapidly with the B.M.E.P.

(2) At constant B.M.E.P. the temperatures rise with decrease in r.p.m.

(3) At constant r.p.m. and B.M.E.P., the engine temperatures remain practically constant over the scavenging range of 125 to 200 per cent. This shows that the scavenging of this engine is already very complete for relatively small air consumptions.

(4) The maximum deflection of the piston crown amounted to about 0.3 mm. and the deflection/crank angle diagram corresponds closely to that of the normal indicator diagram. From a comparison of this with the permanent deflection due to thermal expansion of the piston, it is deduced that the thermal stresses are about three times those due to gas pressure.

The Future of Safety Fuels in Spark Ignition Aircraft Engines. (F. C. Mock, Paper at S.A.E. National Aircraft Meeting, December, 1939.) (76/26 U.S.A.)

The various safety fuels have from 3-7 per cent. less heat value than standard petrols and must therefore be burnt very completely. The volatility of safety fuels is naturally low, but complete vaporisation only calls for 7.5 per cent. of the normal jacket loss and the exhaust gas residue in the engine contains about half the heat required for this purpose. The cooling effect of the vaporisation process should react favourably on engine design and render possible the utilisation of larger pistons and exhaust valves. (According to the N.A.C.A., best results are obtained with direct cylinder injection, spraying horizontally across the chamber and utilising a large valve overlap.)

Although a large amount of preliminary work has been done, the author estimates that a considerable time ($\sim 2\frac{1}{2}$ years) would be required before an aircraft engine of this type would be ready for flight tests. At the same time he is of the opinion that the safety fuel equipment would weigh at least 2-2$\frac{1}{2}$ times that of the standard fuel system. The fuel economy will certainly not be improved, and in view of the present craze for speed, the question arises whether these drawbacks are not too high a price to pay for reduction in fire hazard.

Data on Ethyl Gasoline Corrosion. (Goldowsky, Rept. No. 9, Bull. Soc. Royale des Ingénieurs et des Industriels, Brussels, 1939.) (76/27 Belgium.)

For successful corrosion tests all conditions should correspond to those of the metal's future use. Test samples should even be in the shape of the pieces studied, including rivets, solder, and other parts with which they are associated.

If a sample of light metallic alloy is placed in ethyl gasoline no corrosion occurs. However, it is found that tanks are always perforated at the bottom, never at the top. Water always enters when the tanks are filled. This water, accumulating at the bottom, is responsible for corrosion, which occurs only with light alloys. With rustless steel, the reverse phenomenon is found and only the parts bathed by gasoline are attacked.

Experiments show that gasoline loses its corrosive power in proportion to the duration of agitation and that the corrosive power of water increases. The phenomenon can be explained thus: The ethyl gasoline contains tetraethyl lead

and ethylene bromide. In the presence of water the ethylene bromide hydrolyses and produces a very corrosive acid medium.

Characteristics of Diesel Fuels Influencing Power and Economy. (A. J. Blackwood and G. H. Cloud, J.S.A.E., Vol. 46, No. 2, Feb., 1940, pp. 49-53.) (76/28 U.S.A.)

The only important properties of Diesel fuels which affect engine power and economy are calorific value, ignition quality and possibly viscosity. The present paper reports data obtained from an extended fuel research programme investigating the power and fuel economy obtained when using fuels differing in their physical and chemical characteristics. The main results arrived at are:—

1. Assuming complete combustion, fuel volatility affects the consumption per brake horse-power hour only indirectly, in so far as it is related to calorific value and ignition quality.

2. Most modern engines have fixed ignition timing and, on such engines, ignition quality is a major factor in determining volumetric fuel economy in the upper speed ranges. At lower engine speeds calorific value is the most important consideration.

3. Fuel viscosity in itself is not an important factor in determining the power obtained from a high speed Diesel engine, except in instances where worn injection equipment may make it undesirable to use a low viscosity fuel.

Fundamental Mechanical Aspects of Boundary Lubrication. (H. Blok, J.S.A.E., Vol. 46, No. 2, Feb., 1940, pp. 54-68.) (76/29 U.S.A.)

The physico-chemical aspects of boundary lubrication have already been investigated fairly thoroughly, but lack of information on the fundamental mechanical aspects is a great handicap in applying the physico-chemical results to the intelligent selection of lubricants and materials. On the assumption that pressure and temperature in the region of contact between the rubbing surfaces are the basic mechanical factors, it is shown that four main types of boundary lubrication should be distinguished:—

1. Low pressure and temperature boundary lubrication, or mild boundary lubrication.
2. High temperature boundary lubrication.
3. High pressure boundary lubrication.
4. High pressure and temperature boundary lubrication, or extreme boundary lubrication.

Up to now type 4 has been called "extreme pressure lubrication," but the term now proposed should be adopted, since in this region of boundary lubrication it is more the extreme temperatures than the extreme pressures which are decisive. Moreover, confusion with high pressure boundary lubrication (type 3) can then be avoided.

Phenomena characteristic of each of the four main types of boundary lubrication are discussed.

An appendix deals with frictional (*i.e.*, tangential) vibrations of rubbing surfaces.

Effect of Supercharging on the Comparative Evaluation of the Anti-Knock Properties of Fuels. (M. M. Maslenikov and G. E. Bliessnukov, Aeron. Eng., U.S.S.R., Vol. 13, No. 11, Nov., 1939, pp. 30-9.) (76/30 U.S.S.R.)

Experimental data obtained with a modified Waukesha fuel testing engine shows that when an engine is supercharged the knock tendency of various fuels does not alter to the same extent, since it depends on their chemical constitution; the anti-detonating effect of ethyl fluid apparently does not depend on induction pressure. Of the hydrocarbon groups constituting the fuels tested, the un-

saturateds show best anti-knock stability in the case of supercharging. Naphthenes and aromatics show approximately the same anti-knock stability—inferior to that of the unsaturateds, and the paraffins show the worst behaviour. Thus the results obtained by comparison of the anti-knock properties of fuels, which sharply differentiate the behaviour of paraffin—and unsaturated hydrocarbons, depend on the pressure of the air admitted to the engine.

Evaluation of the anti-knock properties of fuels by the C.F.R. engine method will characterise the value of the fuels for use in a supercharged engine only when there is a small difference between the contents of the fuels in paraffin and unsaturated compounds. For a larger difference a fuel of different octane rating will be required for use with supercharging; results of the present work show that this difference in octane rating may amount to four units.

Effect of Temperature on Lubricating Films. (D. Tabor, Nature, Vol. 145, No. 3669, 24/2/40, p. 308.) (76/31 Great Britain.)

The friction apparatus of Bowden and Leben has shown that when clean steel surfaces slide on one another, the motion is irregular, sticking alternating with slipping. This phenomenon persists in the presence of a non-polar lubricant such as medicinal paraffin oil, although the average value of the friction is reduced. Long chain fatty acids will produce continuous sliding which can also be produced if non-polar oils are heated (oxidised).

This oxidation becomes appreciable for most oils at temperatures above 150°C., and the change in friction characteristics is irreversible on subsequent cooling.

Recent work on some commercial oils giving continuous sliding at room temperatures has revealed a new effect. With these oils, stick-slips are produced when the oil is warmed to between 40 and 80°C., and the effect is reversible, provided the heating has not been sufficiently long to produce appreciable oxidation. It appears that this temperature effect is connected with the desorption or disorientation of the boundary lubricating film and the film is the more strongly absorbed the higher the critical temperature. Similar effects have also been noted with pure fatty acids.

Protective Greases for Aeroplane Engines. (V. A. Yakhlakov, Aviapromyschlennost, Nos. 7-8, 1939, pp. 9-24.) (76/32 U.S.S.R.)

The corrosion of inside surfaces of aero engines and the characteristics of various protective greases are discussed. Tests have been carried out with the two following greases for protecting the internal and external engine surfaces respectively:—

1. Butyl alcohol 10 per cent., aluminium stearate 10 per cent., triethanolamine 6.5 per cent., and lard 73.5 per cent.
2. Oil 98 per cent., triethanolamine oleate 1.5 and triethanolamine 0.5 per cent.

The tests were carried out on various metals and from the results obtained it is claimed that these greases are equal to those of the Ethyl Gasoline Corporation.

Stability of Crankcase Oils (with Discussion). (W. F. Weiland, Trans. A.S.M.E., Vol. 62, No. 2, Feb., 1940, pp. 125-132.) (76/33 U.S.A.)

In this paper the author attempts to answer two vital questions concerning lubricating oils, *i.e.*, performance and useful life. Oxidation and corrosion tendencies constitute the major elements in the deterioration of crankcase oils. The essential requirements for conducting oxidation tests are outlined in the paper and the procedure and results of tests are indicated. Observations on the behaviour of oils in service also offer a means for predicting oil performance. Acid vapour tests to determine oil breakdown are discussed and the results of corrosion studies detailed.

Physical Properties of Some Purified Aliphatic Hydrocarbons. (D. B. Brooks, F. L. Howard and H. C. Crafton, Jr., Bur. Stan. J. Res., Vol. 24, No. 1, Jan., 1940, pp. 33-45.) (76/34 U.S.A.)

In an investigation of the suitability of various paraffin hydrocarbons as constituents of aviation fuel, which is being conducted for the National Advisory Committee for Aeronautics, the Navy Bureau of Aeronautics, and the Army Air Corps, four olefin (di and trimethyl butanes) and seven paraffin hydrocarbons (di and trimethyl butanes, ethyl and trimethyl pentanes and *n*-heptanes) have been obtained in a state of high purity. Eight of these materials were synthesised, one was isolated from a commercial synthetic crude, and two were obtained from commercial sources. All were purified by distillation in automatically controlled fractionating columns of high efficiency.

The measured physical properties of these materials included freezing point, boiling point and its variation with pressure, refractive index and density and their variations with temperature.

Lead—Sensitivity of Motor Fuels and its Dependency on Chemical Composition. (O. Widmaier, Autom. Tech. Zeit., Vol. 43, No. 3, 10/2/40, pp. 63-8.) (76/35 Germany.)

The lead sensitivity of various motor fuels, *i.e.*, the extent to which their knock rating is increased by addition of tetra-ethyl lead, depends on their chemical composition. Paraffin hydrocarbons are most sensitive. Hydrocarbons which on account of their good anti-knock properties are blended with fuels of lower knock rating, respond in different degrees to addition of lead tetra-ethyl. Thus, for example, knock rating is increased to the greatest extent by addition of ethyl fluid to petrol containing isopropyl ether. Fuel mixtures containing iso-octane and iso-pentane are also very sensitive, but blends containing alcohol and benzol respond very little to addition of lead tetra-ethyl. In many cases the knock rating of leaded fuels can even be lowered by addition of alcohol. Lead deposits are formed during storage of leaded fuels, the formation being particularly influenced by light. During use, they also cause corrosion of the cylinder head and base of the piston. However, these disadvantages, which can be partly eliminated, are more than compensated by the greater power and reduced fuel consumption obtained with leaded fuels. It is not yet clear how they affect deterioration of the lubricating oil. (24 references.)

Friction Losses in Ship Propeller Shaft Bearings (Review of German and Dutch Experiments). (W.R.H., Vol. 21, No. 4, 15/2/40, pp. 39-45.) (76/36 Germany.)

The ship propeller shaft is usually supported on a number (11-17) of oil lubricated bearings placed between the thrust block (at engine end of shaft) and the stuffing gland at the propeller end. The friction losses in the oil lubricated bearings is generally assumed to be of the order of 0.3 per cent. of the i.h.p. per bearing, giving a 5-7 per cent. loss for this part of the shaft. These figures have been confirmed by German experiments in which the torsion of the shaft was measured immediately in front of the first bearing and between the last bearing and the stuffing box. The difference between these two readings gives the total friction torque, from which the friction as a percentage of the i.h.p. can be readily calculated. Recent Dutch experiments lead to considerably lower values ($\sim$ 1/10) and the discrepancy has led to an interesting discussion. In the Dutch tests the overall twist of the whole shaft was measured and the torque compared with the passing into the first section. As the German reviewer, however, points out, this method underestimates the true loss which, in the case of a uniformly graded friction drop along the shaft, amounts to twice the measured loss. Even with this multiplication, however, the Dutch friction losses are smaller than

those generally accepted, and must result either from errors in measurement or less strenuous conditions of the tests (shafts not deformed by motion of ship).

The Principle of Mechanical Similarity Applied to Lubricating Films. (A. A. Capoccia, Ricerche di Ingegneria, Vol. 7, Sept.-Oct., 1939, pp. 158-62.) (76/37 Italy.)

The method of dimensional analysis is used to establish a series of relationships expressing the frictional resistance, film thickness, dynamic coefficient of friction, moment, and energy wasted in terms of the non-dimensional ratio (surface × pressure)/(velocity × viscosity). It is shown that when any two of the quantities velocity, viscosity or pressure are kept constant and the third or any one of the other characteristic quantities is varied, the ratio between two values of any characteristic is some whole power (positive or negative) of the above ratio. The general theory is applied to special cases such as sliding and rolling friction, and it is shown to be applicable to the important problem of determining the physical qualities of a lubricant which will give satisfactory results under given mechanical conditions.

(From Science Abstr. " B," Vol. 43, No. 506, 25/2/40, p. 49.)

Low Lead-Silver Alloys for Bearings. (R. W. Dayton, Metals and Alloys, Vol. 10, 1939, pp. 306-10, 324.) (76/38 Great Britain.)

Alloys containing > 3.5 per cent. lead are very resistant to seizure. A corrosion test on specimens rotating in aërated oil containing 1 per cent. of oleic acid at $\sim 160°$ showed complete resistance and an increased seizure-resistance of the specimens. Addition of lead is shown to improve the mechanical properties of silver. Photomicrographs of cast and annealed alloys are given; intergranular cracking is observed in the latter when lead is excessive (4.68 per cent.). Electrodeposition of the Pb-Ag alloy on to the steel backing (from a silver cyanide bath containing lead acetate) is very satisfactory. Preliminary bearing tests made on such plated specimens gave very promising results. The application of bearing alloys with 3-4 per cent. lead in aeroplane engines is indicated.

(From Brit. Chem. Abstr. " B," Vol. 59, No. 1, Jan., 1940, p. 46.)

Plastic Flow in Metals. (H. W. Swift, Metal Industry, 2/2/40, pp. 127-130.) (76/39 Great Britain.)

The various factors involved in the phenomenon of plastic flow and the present state of knowledge on the subject are discussed. Conditions which cause elastic breakdown, plastic flow, and fracture, are mentioned, and the importance of treating these three phenomena as entirely distinct and independent, is stressed. The relationship between stress and strain under plastic conditions is discussed, and also the phenomenon of strain hardening. Note is made of the fact that plastic strain is a function of time, as well as a function of stress, and is also dependent on the previous strain history of the material; the problem of correlating the stress and strain circle diagram under various conditions of combined stress is considered.

(Abstract supplied by Met. Vickers Research Department.)

On the Design of Shell Bodies of Revolution Possessing Constant Strength in all Directions when Subject to a Constant External or Internal Pressure. (F. Tolke, Z.A.M.M., Vol. 19, No. 6, Dec., 1939, pp. 338-343.) (76/40 Germany.)

Shell bodies of revolution of constant strength under a given type of loading (gravity, gas pressure, etc.) are becoming of increasing interest from the point of view of aircraft structures. The theory of such structures is rather involved and necessitates a step by step graphical or numerical integration of the corre-

sponding differential equations. It is thus difficult to obtain general relationships and as a first attempt to classify the subject, the author limits himself to the consideration of shell structures of revolution under constant external or internal pressure. In this case the differential equations can be integrated directly by means of elliptic functions (Legendre Normal Integrals) if the shell is free from bending stresses, *i.e.*, becomes the equivalent of a membrane. The geometrical form of the generating curves is discussed and tables are given showing the variation in the constant stress with wall thickness shape and pressure.

It is thus possible to choose a shape which will ensure the best utilisation of the material under given conditions.

Local Instability of Columns with I-, Z-, Channel, and Rectangular Tube Sections. (E. Z. Stowell and E. E. Lundquist, N.A.C.A. Tech. Note No. 743, Dec., 1939.) (76/41 U.S.A.)

Charts are presented for the coefficients in the formulas for the critical compressive stress at which cross-sectional distortion begins in thin wall columns of I-, Z-, channel, and rectangular tube sections. The energy method of Timoshenko was used in the theoretical calculations required for the construction of the charts. The deflection equations were carefully selected to give good accuracy.

The calculation of the critical compressive stress at stresses above the elastic range is briefly discussed. In order to demonstrate the use of the formulas and the charts in engineering calculations, two illustrative problems are included.

Study of an Apparatus for Studying the Ageing of Cellulose Varnishes by Light. (J. Grard, Pub. Sci. et Tech., No. B.S.T. 88, 1939, 11 pp.) (76/42 France.)

Numerous researches have shown the predominant effect of light in causing deterioration of cellulosic coverings of aircraft surfaces, and thus a light exposure test appears fundamental in investigating ageing of cellulose products. Mercury arc lamps have previously been used for this purpose, but the radiation from this type of lamp is not comparable with solar radiation. The difficulties associated with use of " Sunlamps," due to the variation in radiation intensity produced on a plane surface and caused by the shape of the light source itself, have been overcome by using two lamps in conjunction with a cylindrical reflector of ellipsoidal cross-section, arranged in such a manner as to give a concentration of intensity on the second focal line of the reflector. Application of the apparatus, which is described in detail, to the study of nitro-cellulose and aceto-cellulose films shows that the latter have a considerably higher resistance to the radiation from " daylight " lamps, a result in agreement with practical experience.

It is considered that the apparatus represents a considerable improvement on current practice.

Aeroplane Dopes. Relation of Tautening and Weathering Qualities to Composition. (F. W. Rheinhart and G. M. Kline, Ind. and Eng. Chem. (Industrial Ed.), Vol. 32, No. 2, Feb., 1940, pp. 185-193.) (76/43 U.S.A.)

In a previous report on developing a fire-resistant aeroplane dope to replace the hazardous cellulose nitrate product, formulæ for experimental dopes for application to fabric-covered test panels were selected on the basis of the effect of plastic, plasticiser, solvent, and diluent components on the shrinkage and flexibility of dope films. This report describes the exposure tests of these experimental dopes and discusses the relation between the tautness and weathering properties of the doped fabrics and the composition of the dope.

Evidence is presented to show that the hydroxyl content of cellulose mixed esters is especially critical in determining their suitability for use in aeroplane dopes. Solvent combinations and plasticisers which yield optimum tautness, resistance to slackening in wet weather, and least variation in tautness during

exposure are indicated for various cellulose derivatives. A close correlation is shown to exist between the properties of the unsupported films and the behaviour of doped fabrics; a considerable saving thus results in time, labour, and materials in evaluating new compounds and formulæ.

Spot Welding of Light Alloys (from a Publication Issued by Philips Industrial (Philips Lamps, Ltd.)). (Engineer, Vol. 169, No. 4389, 23/2/40, pp. 189-90.) (76/44 Great Britain.)

The difficulties of welding light alloys arise from the fact that they are good conductors of heat, of low melting point and easily liable to corrosion when heated. The structure of some light alloys alters above a certain temperature and special heat treatment is necessary to restore the normal condition. Moreover, after long exposure to air, light alloys become coated with a thin film of oxide which has a variable resistance value. This film should be removed by pickling in suitable acid shortly before welding. The main conclusions of the present report are:—(1) Light alloys must be welded with high electrode pressures to obtain regularity and to avoid rapid deterioration of the electrodes; (2) the quantity of heat supplied to the weld must be carefully controlled, this can only be done with an electronic interrupter or by an efficient storage device; (3) storage condenser machines are very convenient in operation, since their charge is automatically limited by the peak voltage of the supply; (4) welding at very high speeds offers no advantage and can cause metal projection between the parts. On the other hand, unduly long current time increases the power consumption and leads to distortion of the work; (5) the condenser method has the advantage that the discharge time can be controlled without use of a resistance and thus without lessening efficiency. The discharge curve can be made to extend over $1/10 \sim 1/50$ seconds, and these times seem to be the most favourable.

The Combined Bending-Tension Test for Metals. (E. Mohr, Z.V.D.I., Vol. 84, No. 3, 20/1/40, pp. 49-52.) (76/45 Germany.)

This test is usually applied by bending small test pieces of equal dimensions (sheets, bands or wires) backwards and forwards over rollers, through a small angle, with simultaneous application of a static load, until breakage occurs. The test is carried out on several samples under different loads and a curve plotted showing number of bendings required for breakage against the static stress. These curves show a turning point; the stress corresponding to this point, the bending-tension strength, appears to give a value characterising the alternating bending fatigue strength. In evaluating experimental data the experimental conditions (diameter of rollers, thickness of specimen, angular bending deflection) must be stated since these affect the results. A bending-tension test can be carried out in about two hours, which gives the method particular value.

Complete bending-tension curves, plotted over the whole stress, range from zero up to breaking stress, give valuable information regarding the resistance to deformation and deformability of a material under alternating stressing, and regarding the uniformity of its structure.

Experimental data obtained with various alloys are analysed and discussed.

Micro Tearing Machine for the Photomicrographic and Microcinematographic Examination of Materials. (T. Pöschl, Arch. Eisenhüttenw., Vol. 13, 1939, pp. 189-92.) (76/46 Germany.)

A small, but very strongly constructed machine for tensile tests is described. This is particularly suitable for enabling phenomena at and beyond the flow limit, and the flow of materials itself, to be observed in detail. A continuous observation of the changes in fine structure, due to mechanical stresses and impacts is also possible. Numerous micrographs taken during a bending test are reproduced.

Measurement of the Permeability of Rubber to Various Gases. (A. S. Carpenter and D. F. Twiss, Ind. and Eng. Chem. (Analytical Ed.), Vol. 12, No. 2, 15/2/40, pp. 99-108.) (76/47 U.S.A.)

The rate at which a gas passes through a sheet of rubberlike material and the rate at which a gas is absorbed by a block of the material are both dependent upon the same factors, solubility and diffusion constant. The magnitude of these factors can be measured by absorption experiments carried out under specified conditions and the results can be used to assess the permeability of the material in sheet form. Experimental methods and suitable apparatus are described for following absorption and the manner of interpreting the results in terms of permeability is given. Besides such advantages as accurate temperature control, convenient size and ease of handling of the apparatus, the small size of the test piece, and the elimination of the difficulty of producing uniform thin sheets free from pinholes, the method has the advantage that both factors, solubility and diffusion constant, can be assessed independently; this is not normally possible with direct permeation measurements. Some experimental results are tabulated.

Electric Spot and Seam Welding of Light Alloys. (C. Haase, Z.V.D.I., Vol. 84, No. 6, 10/2/40, pp. 89-96.) (76/48 Germany.)

Electric welding of light alloys still presents difficulties, mainly because the much lower electric resistance of the light alloy prevents the seam being maintained at the requisite temperature unless very much greater current densities are employed (30,000 to 45,000 amps). These currents can only be maintained for a very short time (~ $\frac{1}{5}$ sec.), otherwise the material undergoes structural changes and the electrode is affected. The current control can be carried out purely electrically by means of valves (thyratrons), or mechanically by means of a special cascade transformer. The latter method is more robust and requires less skilled attention. A single one of these modern transformers will operate simultaneously four spot welding or two seam welding machines, which reduces operative costs and produces a more favourable electric loan on the supply system.

The electrode pressure must also be adjustable to suit the work in hand (~ 100 to 300 kg.) and after the optimum values of these three factors have been determined, the electric circuit and welding machine must be able to work over relatively long periods under these conditions to ensure consistency of the weld.

The experiments described show how these factors vary for sheet metals of different thicknesses and composition as well as the resulting fatigue strength of the weld. Both ultimate and fatigue strength of such welded structures compare favourably with standard riveting. A welded fuselage can be completed in half to quarter of the time required for riveting. This new method of construction will require certain changes in design, but its obvious advantages ensure the future of welded light alloy structure as soon as the data on strength characteristics are complete.

Superpressed Plywood, Bonded with Thermosetting Synthetic Resin Adhesives. (R. K. Bernhard, T. D. Perry and E. G. Stern, Mech. Eng., Vol. 62, No. 3, March, 1940, pp. 189-95.) (76/49 U.S.A.)

A series of tests has been carried out to determine the most effective means for manufacturing superpressed plywood, using common species of wood and a synthetic resin of the phenol-formaldehyde type. This type was selected on account of its proved durability under many conditions. The effects of the following major variables were studied:—Thickness of veneer layers $\frac{1}{8}$ to 1/48 in.; common species of wood such as birch, yellow poplar and red gum; increasing pressures 200-1,500 lb./sq. in.; number of layers of resin film, 1-3; number of cross layers, alternate, every fifth and every tenth. The results showed that:—(1) Veneer thickness affects strength of superpressed plywood considerably.

(2) Birch plywood is much stronger than poplar or gum plywood when manufactured under a pressure of 500 lb./sq. in. (3) Poplar and birch superpressed plywood have similar high strength values when manufactured at about 1,500 lb./sq. in. The strength increment for the same materials varies between 66 and 127 per cent. for plywood made under 200 and 1,500 lb./sq. in. respectively. (4) The amount of synthetic resin influences the strength of the bond. (5) The arrangement of cross layers affects the strength data to such an extent that this factor should be considered in designing for specific purposes. (6) The strength of superpressed plywood increases in direct proportion to its density. (7) The strength of superpressed plywood may be adapted to its proposed function, because its strength can be determined with a fair degree of accuracy.

The Effect of Range of Stress on the Torsional Fatigue Strength of Steel. (J. O. Smith, Univ. Illinois Eng. Expt. Station Bull., No. 316, 1939, 38 pp.) (76/50 U.S.A.)

The effect of range of stress on the torsional fatigue strength of steel containing the following constituents: Carbon 0.37 per cent., Mn. 0.75 per cent., PO. 17 per cent., S 0.030 per cent., Si 0.178 per cent., Ni 1.33 per cent., Cr 0.05 per cent., was investigated. The influence of a notch, hole, fillet, keyway, or other type of " stress raiser " on the shearing endurance limit was determined. The formulæ for computing the endurance limit for any range of stress in torsional shear are discussed and classified.

(From Sci. Abstr. " B," Vol. 43, No. 506, 25/2/40, p. 54.)

Fatigue Tests of Connection Angles. (W. M. Wilson and J. V. Coombe, Univ. Illinois Eng. Expt. Station Bull., No. 317, 1939, 24 pp.) (76/51 U.S.A.)

The fatigue strength, that is, the maximum stress to which the part may be subjected 2,000,000 times without failure, was determined for a number of angle parts and riveted parts. The specimens were tested on a cycle in which the total load on the specimen varied from zero to a maximum tension. The fatigue strength of rivets was obtained as the quotient by dividing the total external load that produced the failure in 2,000,000 cycles by the nominal area of the section of all tension rivets. Diagrams are given showing the methods of computing flexural stress and deflection, and deflection of angles due to load causing tension in rivets.

(From Sci. Abstr. " B," Vol. 43, No. 506, 25/2/40, p. 54.)

An Improved Electric Hygrometer. (F. W. Dunmore, Bur. Stan. J. Res., Vol. 23, No. 6, Dec., 1939, pp. 701-14.) (76/52 U.S.A.)

The psychrometer and hair hygrometer are common means of determining the moisture content of air. There are, however, many circumstances to which these are not well adapted, especially in the measurement of upper air humidities by means of the radio sonde, where marked and sudden changes of humidity are encountered.

This paper describes a type of electric hygrometer which better fulfils the above requirements. It covers improvements made in an earlier type of electric hygrometer previously described by the author. The improved unit consists of an 0.01 inch wall aluminium tube $1\frac{11}{16}$ inches long coated with polystyrene resin and wound with a bifilar winding comprising 20 turns (of each wire) per inch of No. 38 AWG bare palladium wire. The unit is then coated with a thin film of partially hydrolysed polyvinyl acetate with the addition of a small amount of lithium chloride, the amount depending upon the humidity range to be covered by the unit. The electric resistance of the film between the two coils is a function of humidity.

The thin walled aluminium tube enables the unit to assume quickly the temperature of the air, as it must if measuring relative humidity. The use of palladium

wire eliminated a continuous ageing effect or increase in resistance caused by a film which continued to form on the surface of all other wires previously used. The polystyrene resin forms an excellent water resistant surface of high electric resistance for the wire and water sensitive film. This construction eliminated hysteresis effects previously experienced, caused by the adsorption of water by glass and other materials used as bases.

A calibration of a three-element unit used in the radio sonde circuit serves as an example of measurements over temperature range from $+30°$ to $-60°$C.

Electric hygrometer units have been made which have not varied more than two or three per cent. over a period of several months.

Corrugated Metal Diaphragms for Aircraft Pressure Measuring Instruments. (W. A. Wildhack and V. H. Goerke, N.A.C.A. Tech. Note No. 738, Nov., 1939.) (76/53 U.S.A.)

A large number of corrugated diaphragms of beryllium copper, phosphor bronze, and Z-nickel, having geometrically similar outlines, but of various diameters and thicknesses, were formed by hydraulic pressing. The apparatus and the technique used in the manufacture, the testing, and the heat treatment are described.

The shape of the diaphragms was such that the central deflections were nearly proportional to the differential pressures up to deflections of 2 per cent. of the diameter. The pressure deflection characteristics of the various diaphragms were correlated with the thickness, the diameter, and the elastic properties by dimensional analysis to obtain formulas and charts applicable to the design of similar diaphragms. The formula

$$FX/PD = 2.25 \times 10^5 \{ (t \times 10^3)/D \}^{-1.52}$$

holds for values of $(t \times 10^3)/D$ over the range from 1 to 4. Outside this range, the exponent is larger. In the formula, t, D, and X refer to the thickness, the diameter and the central deflection of the diaphragm, respectively; P refers to the differential pressure causing the deflection X; and F, a function of the elastic moduli, has the values 18.9, 17.5, and 28.4×10^6 pounds per square inch for beryllium copper, phosphor bronze, and Z-nickel, respectively.

For comparison, some data are presented for flat diaphragms and for corrugated diaphragms differing slightly from the standard design. The use of the experimental results in the selection or the design of corrugated diaphragms is briefly discussed.

The Development of Electrical Strain Gauges. (A. V. de Forest and H. Leaderman, N.A.C.A. Tech. Note No. 744, Jan., 1940, 37 pp.) (76/54 U.S.A.)

The design, construction and properties of an electrical resistance strain gauge consisting of fine wires moulded into a laminated plastic are described. These gauges have dimensions of about 3 in. $\times \frac{3}{8}$ in. $\times$ 0.010 in., and temperature compensation is effected by having wires with positive and negative temperature coefficients of resistance arranged in series or in parallel. At present the results obtained are not always reproducible, possibly due to overheating of the wires, overstraining of the wires on cooling, imperfect cementing of the wires in the gauge or of the gauge itself. The sources of these errors are under investigation, and when the correct conditions have been established it is proposed to make jigs for the production of temperature compensated gauges of about 250 ohms resistance for use on impact work. Short gauge length gauges for work on stress concentrations are also being considered.

The methods of moulding wires into plastic materials are described.

The programme of future work in this field consists in the standardisation and quantity production of wire type resistance strain gauges and development of cold cementing methods and methods of instrumentation suitable for use in the field.

Sensitive Aneroid Diaphragm Capsule with No Deflection Above a Selected Pressure. (W. G. Brombacher, V. H. Goerke and F. Cordero, Bur. Stan. J. Res., Vol. 24, No. 1, Jan., 1940, pp. 31-32.) (76/55 U.S.A.)

A sensitive diaphragm capsule has been designed in which the two corrugated diaphragms nest into each other at external air pressures above a desired value. Evacuated capsules of this type have particular application in measuring pressure with radio sondes of the Diamond-Hinman-Dunmore type, where the deflection of the contact arm is fixed. At the ground level the diaphragms are designed to nest into each other and deflection does not begin until the air pressure is reduced to the value called the cut-off pressure. Several elements of two capsules each were constructed with a cut-off pressure of 140 millibars. When installed in a radio sonde in place of the usual type, which is responsive over the entire range of pressures, a sevenfold increase in sensitivity in pressure measurement was obtained at altitudes above 46,000 feet.

Flightray (Blind Flying and Landing Indicator). (Inter. Avia., No. 699, 27/2/40, pp. 1-5.) (76/56 U.S.A.)

This instrument (Sperry Gyroscope Co.) shows the readings of four navigational instruments simultaneously as an optical pattern on the fluorescent screen of a cathode ray tube. The instruments are:—I. Artificial horizon shown by a straight line, up and down motion of which means dive or climb, whilst a tilt indicates banking. II. Directional gyro turn about the vertical axis is shown by deviation of a short vertical line on the upper part of the screen. III. Radio compass (or localiser path): A small circle of light is able to travel all over the screen; its central position indicates " on path " conditions and deflection to left or right shows deviation from the radio compass heading. Up or down deflection shows change in altitude or deviation from the glide path in blind approach. IV. Air speed indicator: A small horizontal line rises across the screen with increase in speed. A black mark on the lower half of the screen acts as a stall warning indicator.

A miniature aeroplane is silhouetted in the centre of the screen and the real aircraft is kept to normal altitude, position and heading by ensuring that the luminous circle surrounds the fuselage of the silhouette and the horizontal lines coincide with the span. Each of the master instruments thus " televised " is fitted with a special pick-up transforming the deviation of the pointer into a differential alternating voltage, which, after rectification and amplification, deflects the corresponding optical pattern in the cathode ray tube. The four patterns are seen simultaneously without flicker.

The " Flightray " has been undergoing development since 1937 and several units will shortly be available for extensive service trials.

Note on the Distributions of Temperature and Vapour Pressure Around a Horizontal Wet Cylinder. (R. W. Powell, Phil. Mag., Vol. 29, No. 194, March, 1940, pp. 274-284.) (76/57 Great Britain.)

Experiments are described in which unventilated thermocouple psychrometers are used to determine the temperature and vapour pressure distributions above, below, and to one side of the wet surface of a horizontal cylinder. The presence of a convection current passing over the surface in a downwards direction is revealed when the surface is cooled to a temperature well below that of the air. When the surface temperature is raised, a temperature is reached at which very little movement of the air occurs. Under the conditions of the present experiment this occurred when the surface temperature was just over 1°C. below the temperature of the surroundings. With further increase in surface temperature the convection currents change to an upward direction. It is shown that the rate of evaporation falls to a minimum value in the region of little air movement, and, on the assumption that the whole of the moisture loss takes place by diffusion,

the experimental data for the vapour pressure gradients near the wet surface are seen to lead to values of the correct order of magnitude for the coefficient of diffusion of water vapour into air.

Noise Analysis. A New Laboratory for Noise Investigation. (C. A. Mason, B.T.H. Act., Vol. 15, Nov.-Dec., 1939, pp. 205-11.) (76/58 Great Britain.)

The object of the laboratory is to enable consistent and accurate noise measurements to be made on all classes of electrical products, so that the behaviour of the equipment on site may be predicted by measurements taken before despatch. Important factors are the use of a non-reverberant room or echoless chamber, an isolated base for the machine, and an enclosure which excludes external noises. The building is described; the test-room has its walls and ceiling lined with four inches of glass wool with an air space behind. When a machine is under test, personnel and apparatus, except the microphones, are evacuated, and measurements are made in an adjoining room. The use of subjective and objective instruments for the measurement of equivalent loudness is discussed. The objective meter is preferred, but readings are frequently checked by subjective methods. The instruments used, and analyses of noises, are described and illustrated.

(From Sci. Absts. " B," Vol. 43, No. 506, 25/2/40, p. 88.)

Propeller Rotation Noise Due to Torque and Thrust. (A. F. Deming, N.A.C.A. Tech. Note No. 747, Jan., 1940.) (76/59 U.S.A.)

Sound pressures of the first four harmonics of rotation noise from a full scale two-blade propeller were measured and are compared with values calculated from theory. The comparison is made (1) for the space distribution with constant tip speed, and (2) for fixed space angles with variable tip speed.

CONCLUSIONS.

1. The theory gives values of total power radiated in the first four harmonics within four decibels of experimental values.

2. This study shows that the experimental results are in reasonably good agreement with Gutin's theory. The agreement is particularly good for the lower harmonics, in regard to both magnitude and distribution.

3. For the fourth harmonic, the results differ by as much as eight decibels. This disagreement might be due to disregard of the thickness effect, which, in general, should be greater for the higher harmonics.

4. It has been shown that the power output in rotation noise increases as the $6+5/3\ qn$ power of the tip speed, where

q = order of harmonic,
n = number of propeller blades.

Free Space Propagation Measurements at 75 Megacycles. (G. L. Haller, J. Frank. Inst., Vol. 229, No. 2, Feb., 1940, pp. 165-80.) (76/60 U.S.A.)

In studying the radiation characteristics of aircraft antennas, employing the principle of similitude with scale models, a major problem has been to devise a system of free space propagation measurements in order to eliminate errors caused by proximity to the ground. The ground errors appear in two forms. The first is the actual distortion of the field in both amplitude and phase, and the other is the unequal attenuation of the horizontal and vertical electrical fields. As an aircraft antenna is rather complex and may be made up of both horizontal and vertical components, any unequal attenuation may give a false representation of the true radiation pattern. The original work was done at a frequency of 75 megacycles and at a height of approximately one-half wavelength (2 meters) and serious errors were noted. This paper details the preliminary study and

some of results of a tower system which was built to make free space measurements with little error due to ground effects.

40 *cm. Waves for Aviation.* (Electronics, Vol. 12, Nov., 1939, pp. 12-15.) (76.61 Great Britain.)

Signals of 700 mc./s., modulated at 150 and 90 c./s., respectively, are directed in fan-shaped beams from two horns 26 ft. long. The overlapping signal field provides a glide path for the landing of aircraft. The test described was made with a sender in which the output power of the oscillator was about 1 W. at 700 mc./s. The heterodyne receiver, which produces full-scale output for an input of only 15 μV., employs in the first detector stage a diode which develops the third harmonic of the oscillator frequency (230 mc./s.). Three tuned circuits are connected in series with the diode, tuned to frequencies 700, 230, and 10 mc./s., respectively, 10 mc./s. being the intermediate frequency. Subsequent stages of amplification, which are more conventional, are described. Noise and motor-boating are avoided by the inclusion of resistance-capacitance band-pass couplings, permitting only frequencies from 50 to 400 c./s. to appear in the output. The apparatus has been successfully tested with aircraft.

(From Sci. Absts. " B," Vol. 43, No. 506, 25/2/40, p. 82.)

LIST OF SELECTED TRANSLATIONS.

NOTE.—Applications for the loan of copies of translations mentioned below should be addressed to the Under-Secretary of State (R.T.P.), Air Ministry, Dept. Z.A., London, W.C.2, and will be loaned as far as availability of stocks permit. Suggestions concerning new translations will be considered in relation to general interest and facilities available.

Lists of selected translations have appeared in this publication since September, 1938.

TRANSLATION NUMBER AND AUTHOR.		TITLE AND JOURNAL.
989	Schultz-Grunow, F. ...	*Predetermination of the Separation Point in Turbulent Flow.* (L.F.F., Vol. 16, No. 8, 30/8/39, pp. 425-8.)
1007	Stanke, P.	*External Disturbance of the Path of a Projectile.* (W.T.M., Vol. 42, No. 12, Dec., 1938, pp. 560-9; Vol. 43, No. 1, Jan., 1939, pp. 35-44; No. 2, Feb., 1939, pp. 63-9.)
1008	Seifert, A.	*Comparison of Terms Relative to the Performance of Aero Engines, Employed in Various Countries.* (Luftwissen, Vol. 6, No. 8, August, 1939, pp. 238-241.)
1009	Schmierschalski, H. ...	*Action of Several Propellers on One Shaft.* (W.R.H., Vol. 20, No. 17, 1/9/39, pp. 278-9.)
1010	—	*High Altitude Flying.* (La Guerre Aérienne, Vol. 5, No. 164, 20/11/39.)
1012	Stieglitz, A.	*The Effect of Pendular Masses on Torsional Vibrations.* (Yearbook of German Aeronautical Research, Vol. 2, 1938, pp. 164-178.)

THE ROYAL AERONAUTICAL SOCIETY

WITH WHICH IS INCORPORATED THE INSTITUTION OF AERONAUTICAL ENGINEERS

SEVENTY-FIFTH ANNUAL REPORT OF THE COUNCIL, 1939-1940.

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The following were appointed as the Society's Representatives on other bodies:—

Advisory Committee for Aeronautical Engineering of the City and Guilds of London Institute: Professor F. T. Hill and Captain J. Laurence Pritchard.

Advisory Council of the Science Museum: Lord Sempill.

Air League of the British Empire: Mr. W. O. Manning and Mr. Griffith Brewer

Association of Special Libraries and Information Bureaux: Mr. J. E. Hodgson (Honorary Librarian).

British Gliding Association: Council: Mr. W. O. Manning.

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British Standards Institution, Committee on Symbols and Abbreviations Used in Engineering: Dr. H. Roxbee Cox.

British Standards Institution Technical Committee on Aircraft Nomenclature: Professor L. Bairstow, Captain J. Laurence Pritchard.

British Standards Institution, Units and Technical Data Committee: Lieut.-Col. W. Lockwood Marsh.

Engineering Joint Council: Mr. C. R. Fairey.

Engineering Joint Council. Special Educational Representative: Professor G. T. R. Hill.

The Guild of Air Pilots and Air Navigators of the British Empire, Sefton Brancker Memorial Fund Committee: Captain P. D. Acland.

Joint Standing Committee with the Society of British Aircraft Constructors and the Royal Aero Club: Mr. E. F. Relf, Lord Sempill, Lieut.-Col. J. T. C. Moore-Brabazon, Air Vice-Marshal R. M. Hill, Mr. W. C. Devereux.

National Central Library: Mr. J. E. Hodgson (Honorary Librarian).

Professional Classes Aid Council: Lord Sempill.

Seagrave Memorial Fund Committee: Mr. C. R. Fairey.

Ministry of Labour, Engineering Advisory Committee:

Mr. A. H. R. Fedden, Captain J. Laurence Pritchard.

Institution of Mechanical Engineers, Committee on Splined and Serrated Shafts: Mr. L. Mawer.

Institution of Mechanical Engineers, National Certificates and Diplomas in Mechanical Engineering: Mr. A. H. R. Fedden and Professor F. T. Hill.

Institute of Petroleum—Summer Meeting on Fuels for Internal Combustion Engines: Mr. D. R. Pye.

Society of Automotive Engineers—Conference May 2nd-June 8th, 1939: Mr. F. Handley Page, Mr. E. Hives, Mr. W. C. Devereux, Major R. H. Mayo.

Institution of Civil Engineers—Conference on Engineering Education and Training: Professor F. T. Hill.

British Standards Institution—Conference on the Standardisation of Letter Symbols in Science and Technology: Professor L. Bairstow.

British Standards Institution—Conference on Standardisation of Jewels and Pivots for Instruments: Major B. W. Shilson.

MEMBERSHIP.

The Membership of the Society for 1939 shows a net increase, after allowing for members suspended, of 172 over 1938. The figures in brackets give the membership in 1938.

In 1938 the membership of the Society, for the first time in its history, exceeded 2,000, and is now approaching the 2,500 mark. During the year the Council had under earnest consideration how the membership might still further be increased by making eligible many highly qualified people in the industry who were not at present members. Following certain proposals put forward at the Annual General Meeting in March, 1939, a Rules Committee of Council was appointed, and reported in September, 1939. The outbreak of war prevented,

unfortunately, these proposed new Rules coming before members for ratification at a Special General Meeting until February, 1940, so that their full effect will not be seen until the end of that year.

MEMBERSHIP OF THE SOCIETY, DECEMBER, 1939.

	No. of Members.		Honorary & Life Members.		Suspended.		Total.	
Fellows	178	(167)	22	(22)	2	(1)	202	(190)
Members	48	(50)	1	(1)	1	(1)	50	(52)
Associate Fellows	734	(673)	5	(5)	28	(15)	767	(693)
Associate Members... ...	178	(184)	—	(—)	9	(6)	187	(190)
Associates	273	(256)	3	(3)	22	(15)	298	(274)
Graduates	102	(70)	—	(—)	3	(—)	105	(70)
Companions	109	(113)	10	(10)	7	(6)	126	(129)
Founder Members	18	(22)	1	(1)	1	(—)	20	(23)
Students	614	(550)	—	(—)	58	(47)	672	(597)
Temporary Hon. Members	—	(—)	41	(38)	—	(—)	41	(38)
	2254	(2085)	83	(80)	131	(91)	2468	(2256)
Less Joint Members ...	25	(25)					25	(25)
	2229	(2060)	83	(80)	131	(91)	2443	(2231)

DONATIONS.

The Council have to thank the Air Ministry for the fifteenth year in succession for their generous grant of £250 to the Funds of the Society, and the Society of British Aircraft Constructors, also for the fifteenth year in succession, for a similar donation.

At the end of 1924 the Society was faced with a severe financial crisis. For three years in succession the expenditure had exceeded the income by some £300 a year and the small invested funds accumulated during and directly after the Great War, were practically exhausted.

Sir Henry Tizard, the Chairman of the Society, in presenting the annual accounts, in March, 1925, made the first public reference to the raising of such a sum of money as would " extricate this old and famous Society from its financial difficulties, to set it firmly on its feet, and so help on the development of aeronautics in this country in a way which will be none the less effective because it is not spectacular. This history of all other developments in applied science shows the importance of the existence of a flourishing independent society, which can encourage the free discussion of scientific and technical problems."

The appeal was made at a time when the aircraft industry was struggling for orders and had no profits of its own to share with others, no matter how needy. Thanks, however, largely to the energy of the late Air Vice-Marshal Sir Sefton Brancker, a sum of over £500 was raised during the first year, of which half was given by the then Sir Charles Wakefield.

The years which followed were difficult ones for the industry generally and the fund increased but slowly. It was considerably helped by a legacy from Sir Mackenzie Chalmers, for so many years a Member of Council, of £450. During this period raids on the funds were saved by the great generosity of the Guggenheim Trust Fund, which contributed £1,000 a year for five years to the current expenses of the Society, to the Air Ministry for a grant of £250 a year, a sum which has now been granted for 15 years, and to the Society of British Aircraft Constructors for a similar sum of £250 a year, which has also been granted annually for the past 15 years.

These grants enabled the Society to tide over a most difficult financial period, when the financial situation of the world was deteriorating. In 1930 Mr. C. R.

Fairey, as President of the Society, issued a special appeal which, despite coming at a time when everyone was in difficulties, increased the fund during his period of office by nearly £600. To that sum Mr. Fairey later generously added £2,625.

The financial slump did not show any real signs of recovering until 1937. In that year Mr. H. E. Wimperis, the President, made a number of special personal appeals which resulted in an increase of £34,125 0s. 0d., and the Society was at last visualising the possibility of standing firmly on its own feet.

Immediately following his accession to office in October, 1938, the President, Mr. A. H. R. Fedden, made the increasing of the fund a major issue as a necessary factor before the Society could carry out the many objects which had been discussed by the Council, but held up on financial grounds. These objects, the acquisition of a house of its own, the enlarging of the Journal, the holding of an aeronautical congress, increasing the number of lectures, and many others, could only possibly be carried out if a fund were available, the interest from which would relieve the Society from financial anxiety.

Mr. Fedden's appeal, in a few months of intense activity, resulted in the substantial increase of over £70,000 0s. 0d. to the Fund, a result which is a tribute to his high endeavour and practical interest in the welfare of the Society.

In the brief outline given above, the Presidents of the Society for the time being have been primarily concerned with the growth of the Fund, but there have been many helpers in the field and special mention must be made of two, Mr. F. Handley Page, himself one of the most generous donors, and Mr. W. C. Devereux, Chairman of the Finance Committee, who not only set an example by his own donations, but successfully appealed on behalf of the Society to a number of those whose names appeared in the full list which was published in the January, 1940, issue of the Journal.

Many of the sums given are given in the form of annual donations over a period of seven years, by Trust Deeds, so that the full effect of the magnificent response to the Society's appeal does not immediately appear.

The table below gives the progress of the Endowment Fund up to date:—

	£	s.	d.
December, 1926	575	0	0
December, 1927	597	2	0
December, 1928	1,047	18	0
December, 1929	1,077	6	0
December, 1930	1,265	10	0
December, 1931	1,935	10	0
December, 1932	2,196	2	0
December, 1933	9,716	19	5
December, 1934	10,131	14	11
December, 1935	10,895	10	7
December, 1936	11,138	16	7
December, 1937	11,474	3	7
December, 1938	12,211	12	11
December, 1939	51,048	14	6

PRESIDENT'S LETTER.

Shortly after the outbreak of the War the President addressed the following letter to all members of the Society:—

DEAR SIR,—Early this year the Council decided that annually the newly elected President should open the Autumn Session by an address, and it was to have been my great privilege to be the first to give such an address in October of this year. In this talk I had hoped to tell you something of the Council's intentions for the ensuing fifteen months.

It was hoped that next year would prove to be an important one in the history of the Royal Aeronautical Society. It had acquired new premises worthy

of its prestige; it had an assured income for their maintenance, and it had decided upon holding an International Congress at Stratford-on-Avon in the summer of 1940. The Society would, therefore, assuredly take another step forward in its history of achievement.

But the coming of war has, of course, changed all this. The Council have now decided that I should write you a letter explaining what its action has been and the general policy upon which it has decided since the outbreak of hostilities.

It is appreciated that practically every member of the Society or their relatives will be playing some part or other in prosecuting the war, and that everyone's efforts will be concentrated on carrying this war through to the only possible conclusion, no matter what may be the cost.

The Council have asked me to wish Godspeed to all members in this National work in the sure knowledge and appreciation that the Royal Aeronautical Society, throughout all its branches and grades, is playing a vital part in the conduct of the war.

At the outbreak of war, the Council was called upon to take immediate steps to consider the general policy of the Society and have arrived at the following conclusions.

The archives and valuable papers of the Society have been moved from No. 4, Hamilton Place to a suitable place of safety in the country, where they will remain until the cessation of hostilities.

No. 4, Hamilton Place, the new headquarters of the Society, will be kept open. Captain Pritchard, with a skeleton staff, will remain at No. 4, Hamilton Place. Some of the rooms, including the Library, will be available for the use of members until further notice.

If members have any spare time whatsoever, it is the Council's earnest desire that they should endeavour to make as much use as possible of Hamilton Place whenever opportunity offers.

The lecture programme for the coming Session has been cancelled. It is realised that in wartime everybody is so busy that it is impossible to give sufficient importance to lectures, and that many subjects cannot be discussed with adequate freedom. The Wilbur Wright lecture, however, will take place next May.

If the war continues for a long period, it is hoped that we may be able to consider some curtailed form of lecture programme for the following session.

All the arrangements for the forthcoming International Congress at Stratford-on-Avon, which were making excellent progress, have had to be cancelled, and the services of Colonel Edwards, who was doing good work on behalf of this conference, have had to be dispensed with for the duration of hostilities.

It is most important that the subscription list be kept up, and an endeavour made to increase the membership, and I hope that all members will make a point of paying their subscriptions promptly.

I cannot possibly conclude this letter without referring to the magnificent generosity of a large number of members of the Aircraft and Allied Industries, which has enabled the considerable sum of £109,202 0s. 0d. to be collected. This will ensure that the Society can be continued on a proper financial basis.

I am sure you will agree that the grateful thanks of all members of the Society are due to those who have made this possible, and I would like to record the Council's high appreciation of this generous help. A complete list of the subscriptions towards the funds of the Society will be found in the January, 1940, issue of the Journal.

It is hoped that it will be possible to make another statement in regard to the activities of the Society early next year.

With all good wishes,

Yours truly,

(Signed) A. H. R. FEDDEN,

President.

Society's New Headquarters.

On March 25th, 1939, the Society moved into its new headquarters at No. 4, Hamilton Place. On June 16th and June 17th the President and Council invited all members and their ladies to a Reception and Dance in the new headquarters, so that all would have an opportunity to see their own home, the first in the long history of the Society. A full description of No. 4, Hamilton Place and the list of guests who attended the opening ceremony were given in the Journal for July, 1939.

The opening of No. 4, Hamilton Place marks a new era in the activities of the Society, which, though temporarily postponed in some ways owing to the outbreak of war, will undoubtedly allow the Society to make rapid progress in carrying out many of its projects which were not possible under the cramped conditions of No. 7, Albemarle Street.

Library.

Mr. J. E. Hodgson, Hon. F.R.Ae.S., completed his sixteenth year as Honorary Librarian, and the Council wish to place on record their appreciation of the valuable advice and help he has given about all matters pertaining to the Library.

The general scope of the new library furnishings at 4, Hamilton Place were completed in constant consultation with Mr. Hodgson, and the new Library is admitted to be one of the most beautiful libraries of any engineering or scientific body.

Following the move into No. 4, Hamilton Place, Miss F. Buss was appointed a full-time Librarian, and work was at once put in hand to carry out the much needed reorganisation of the Library. Every book, pamphlet, and document has been re-classified so that it is now possible to find quickly all the available information on any subject. The Technical Index is also being revised in the same way.

During the year many slides, photographs and books have been presented to the Library, and the Council wish particularly to record their appreciation of these gifts.

Garden Party, May 14th, 1939.

The Society held its annual Garden Party on Sunday, May 14th, 1939, at the Great West Aerodrome, near Hayes, the use of which was kindly given to the Society for the day by Mr. C. R. Fairey, M.B.E., F.R.Ae.S., a former President. The attendance of members and their friends was the largest since the function was first inaugurated. Over 6,000 members and guests were present.

The whole of the arrangements on the aerodrome were, as in previous years, carried out by Mr. Fairey and his staff, and the Council wish to pay a tribute to the excellent organisation which allowed the whole programme to be carried through so efficiently. It is very largely due to the really practical and generous help of Mr. Fairey that the Garden Party has become the outstanding aeronautical function of the year.

The Council would like to express their high appreciation of the help given by Flight Lieut. C. S. Staniland and those under him. They were entirely responsible for the flying programme and the arrangements for the static display.

The following programme was arranged:—

2.30—3.0 p.m.—Reception by the President, Mr. A. H. R. Fedden, D.Sc., M.B.E., F.R.Ae.S.
2.50—2.58 p.m.—G. Lowdell. Twin-engined Trainer.
3.0—3.8 p.m.—J. Summers. Wellington.
3.10—3.18 p.m.—Flight Lieut. Bailey. Skua.
3.20—3.28 p.m.—Capt. Percival. Q.6.
D. M. Bray. Mew Gull.
3.30—3.38 p.m.—D. Hollis-Williams. Cygnet, with tricycle undercarriage.
3.40—3.48 p.m.—C. Feather. Defiant.

3.50—3.58 p.m.—F. H. Dixon. P4/34.
4.0—4.8 p.m.—R. A. C. Brie. Type C40.
4.10—4.38 p.m.—Tea interval.

During the tea interval there was a demonstration at 4.10—4.24 by 9 Supermarine Spitfires of No. 74 Fighter Squadron, and at 4.26—4.38 a demonstration by 9 Bristol Blenheims of No. 601 Fighter Squadron of the Auxiliary Air Force.

4.40—4.48 p.m.—Capt. A. M. Kingwill. Willoughby St. Francis. S. Appleby. Schelde Musch.
4.50—5.18 p.m.—Tea interval. During the tea interval there was a demonstration of the following old types of machines:—
R. G. J. Nash. 1911 Bleriot XXVII.
R. O. Shuttleworth. Sopwith Pup. Bleriot Deperdussin.
5.20—5.28 p.m.—Flt. Lieut. G. N. Snarey. Lysander II.
5.30—5.38 p.m.—Brian Allen, A. D. Ward, Capt. J. Youill. 3 Tipsy's.
5.40—5.48 p.m.—A. J. Pegg. Bristol Blenheim.
5.50—5.58 p.m.—C. S. Staniland. Firefly II.
6.0 p.m.—A.R.P. Demonstration.

Dr. Seville Whitehurst was in attendance during the afternoon as the Medical Officer on the Aerodrome.

The following machines, in addition to those of private owners arriving by air, were on the aerodrome, including those which gave demonstrations during the afternoon:—

Arpin Monoplane A.1 Mk. 2. (M. B. Arpin and Co.)
Benez-Mraz Be.550 Bibi. (Aircraft and Allied Enterprises Ltd.)
Blackburn Skua. (Blackburn Aeroplane Co.)
Bloch 220. (Air France.)
Boulton Paul Defiant. (Boulton Paul Aircraft, Ltd.)
Bristol Blenheim Mk. IV. (Bristol Aeroplane Company.)
Chilton (Ford 10 Engine). (Chilton Aircraft, Ltd.)
Chilton (Train 4T Engine). (Chilton Aircraft, Ltd.)
Cierva Autogiro C.40. (Cierva Autogiro Company.)
De Havilland Dragon Rapide. (De Havilland Aircraft Company.)
De Havilland Flamingo. (De Havilland Aircraft Company.)
De Havilland Moth Minor. (De Havilland Aircraft Company.)
De Havilland Tiger Moth. (De Havilland Aircraft Company.)
Douglas D.C.3. (K.L.M., Royal Dutch Air Lines.)
F Class Imperial Airways Air Liner (De Havilland). (Imperial Airways.)
Fairey Battle. (Fairey Aviation Company.)
Fairey Firefly. (Fairey Aviation Company.)
Fairey P.4/34. (Fairey Aviation Company.)
Foster Wikner (1939) Wicko.
General Aircraft Cygnet. (General Aircraft, Ltd.)
General Aircraft Experimental Pressure Cabin Machine. (General Aircraft, Ltd.)
General Aircraft Monospar or Airspeed Courier. (General Aircraft, Ltd.)
Handley Page Hampden I. (Handley Page, Ltd.)
Hawker Hurricane. (Hawker Aircraft, Ltd.)
Lockheed 14. (British Airways, Limited.)
Luton Buzzard. (Luton Aircraft, Ltd.)
Luton Major. (Luton Aircraft, Ltd.)
Messerschmitt Taifun. (Mr. H. J. Aldington.)
Miles Magister. (Phillips and Powis Aircraft, Ltd.)
Miles Master. (Phillips and Powis Aircraft, Ltd.)
Moss Cirrus Minor Trainer. (Moss Brothers Aircraft, Ltd.)

Moss Pobjoy Sports. (Moss Brothers Aircraft, Ltd.)
Percival Mew Gull. (Percival Aircraft, Ltd.)
Percival Q.6. (Percival Aircraft, Ltd.)
Percival Vega Gull. (Percival Aircraft, Ltd.)
Reid and Sigrist Trainer. (Reid and Sigrist, Ltd.)
Stinson Reliant. (Brian Allen Aviation, Ltd.)
Taylorcraft Plus. (Taylorcraft Aeroplanes, Ltd.)
Taylor-Watkinson Ding Bat. (Mr. C. W. Taylor.)
Tipsy Trainer. (Brian Allen Aviation, Ltd.)
Vickers Supermarine Spitfire (Special). (Vickers-Armstrong, Ltd.)
Vickers Wellington I. (Vickers-Armstrong, Ltd.)
Westland Lysander II. (Westland Aircraft, Ltd.)
Willoughby Delta St. Francis. (The Willoughby-Delta Company.)
Bleriot XI (1909). (Mr. R. G. J. Nash.)
Bleriot XXVII (1911). (Mr. R. G. J. Nash.)
Fokker D.VII (1917). (Mr. R. G. J. Nash.)
Deperdussin Monoplane (1911.) (Mr. R. O. Shuttleworth.)
Bleriot XIV. (Mr. R. O. Shuttleworth.)
Sopwith Pup. (Mr. R. O. Shuttleworth.)
Klemm 35B.
Bücker Jungmann.
Fairchild 24.
Auto Trainer. (Mr. A. York Bramble.)
Donkey Trainer. (Mr. A. York Bramble.)
Parnall 382. (Parnall Aircraft, Ltd.)

The Council wish to record their thanks to all those pilots, firms and others who so willingly helped with the display of the above aircraft.

The Council also wish to record their thanks to Mr. W. Courtenay, M.M., A.R.Ae.S., who gave a broadcast description of the events during the afternoon; to the Automobile Association for their organisation of the car and aeroplane park and preparation of a map showing the approaches to the aerodrome; and to Messrs. L. A. Rumbold and their organisation in the aircraft park.

A Static Display was given in one of the hangars, and the Council wish to thank the following for their assistance in making the display of such interest during the afternoon:—

Aeronautical exhibit prepared by Shell-Mex and B.P., Limited, from items taken from their exhibition "See How They Fly"; aircraft accessories, shown by Avimo, Limited; aircraft instruments, shown by Kelvin, Bottomley and Baird, Limited; airscrew blades, shown by Jablo Propellers, Ltd.; airscrews, shown by The Airscrew Company, Ltd.; air survey exhibit, shown by The Aircraft Operating Company, Ltd.; Alvis Leonides Engine, shown by Alvis, Ltd.; brake mechanism, shown by Bendix, Ltd.; Cheetah MKX1 Aero Engine, shown by Armstrong-Siddeley Motors, Ltd.; Cirrus Aero Engines, shown by Blackburn Aircraft, Limited; de-icing equipment, magneto and starter, shown by Rotax, Ltd.; Elektron Magnesium Alloys, shown by Magnesium Elektron, Ltd.; filters, shown by Vokes, Ltd.; fire fighting equipment, shown by Minimax, Ltd.; fire protection equipment, shown by the National Fire Protection Co., Ltd.; fire and splinter-proof shelter, shown by Durasteel Roofs, Ltd.; Gipsy engine and controllable pitch airscrews, shown by De Havilland Aircraft Co., Ltd.; hydraulic aircraft equipment, shown by Automotive Products, Ltd.; hydraulic control system for aircraft, shown by Dunlop Rubber Co., Ltd; lubrication and re-fuelling equipment, shown by Tecalemit, Ltd.; master control carburettor, shown by H. M. Hobson (Aircraft and Motor) Components, Ltd.; model aircraft, shown by Vickers-Armstrong, Ltd.; model of Delta 9G Transport Machine St. George, shown by Willoughby Delta Co., Ltd.; Napier-Halford Dagger, Series VIII, shown by D. Napier and Son, Ltd.; Novellon clear sheeting, shown by British Celanese, Ltd.;

patent compression joints, shown by Simplifex Couplings, Ltd.; retractable landing lamps, shown by Maldon C. Harley and Rotax, Ltd.; retracting undercarriage, shown by Aircraft Components, Ltd.; Rolls-Royce Merlin III Engine; sectioned two-speed supercharger, shown by Armstrong-Siddeley Motors, Ltd.; gyroscopic instruments and anti-vibration mountings, shown by the Sperry Gyroscope Co., Ltd.; Tufnol, shown by Ellison Insulations, Ltd.; wheel and brake equipment, shown by the Palmer Tyre Co.; aircraft accessories and blind approach trainer, shown by the Plessey Co., Ltd., and the Breeze Corporation of Great Britain, Ltd.; A.R.P. incendiary bomb demonstration, by the Hayes and District Urban Council; Hercules engine, sectioned Pegasus, Taurus engine, shown by the Bristol Aeroplane Co., Ltd.; cooling, air conditioning and fuel tank, shown by Gallay, Ltd.; controllable pitch airscrews and model aircraft, shown by the Fairey Aviation Co., Ltd.; riveting systems, shown by Aircraft Materials, Ltd.; ultra-light aircraft, Dart Aircraft, Ltd.; airscrews, shown by Rotol, Limited.

The Council would like to place on record their thanks for the help given by the Air Council in granting permission for certain service machines to be present at the display and to take part in it; and to the Fairey Aviation Company, Limited, for their permission for the Works Silver Band (Stockport Branch) to play during the afternoon under the leadership of Mr. F. Smith.

ANNUAL GENERAL MEETING, MARCH 29TH, 1939.

The following is an abbreviated report of the Annual General Meeting of the Society, held on Wednesday, March 29th, 1939, in the Hall of the Institution of Mechanical Engineers, Storey's Gate, Westminster, at 6.30 p.m.

In the chair—Mr. A. H. R. Fedden, M.B.E., F.R.Ae.S., President of the Society.

Present:—L. R. E. Appleton (Graduate), B. D. Austen (Associate Member), W. E. Baptist, M.Inst.B.E., M.S.A.E., M.I.Ae.S., A.M.I.E.I. (Associate), Griffith Brewer (Honorary Fellow) (Vice-President), S. Camm (Fellow), Squadron Leader S. N. Cole (Associate Fellow), H. Roxbee Cox, Ph.D., D.I.C., B.Sc. (Fellow), W. C. Devereux (Fellow), C. Robson Elgie (Associate), G. A. G. Embleton (Companion), E. G. Fischeles (Associate Fellow), Squadron Leader H. P. Fraser (Associate Fellow), A. Gouge (Fellow), R. C. B. Hendy (Associate Member), Professor F. T. Hill (Fellow), M. Langley (Member), R. L. Lickley, B.Sc., D.I.C. (Associate Fellow), P. G. Masefield, M.A. (Student), N. A. V. Piercy, M.I.Mech.E., D.Sc., A.M.Inst.C.E. (Fellow), Professor A. J. Sutton Pippard, M.B.E., D.Sc., M.I.C.E. (Fellow), C. P. Plantin, B.Sc. (Graduate), B. Shenstone (Associate Fellow), Major B. W. Shilson, O.B.E., M.I.Mech.E. (Fellow), Lieut.-Col. S. Heckstall Smith (Fellow), C. D. Stanley, A.M.I.E.E. (Companion), D. Stevenson (Associate Fellow), P. C. Thornton (Associate Fellow), L. Wingfield, M.C., D.F.C. (Associate).

Capt. J. Laurence Pritchard (Secretary) in attendance.

1. The Secretary read the notice convening the meeting.

2. The President, in presenting the Report of the Council and the Balance Sheet and Income and Expenditure Accounts of the Society, said that it was a very real pleasure indeed that he took the chair for the first time at the Annual General Meeting of the oldest aeronautical society in the world. Next year the Society would be able to hold its Annual General Meeting in its own building.

The purchase, at the beginning of the year, of magnificent new premises at No. 4, Hamilton Place, has been a major event in the history of the Society. He felt that at last the Society had found a home which is worthy of it, a home to which they can invite distinguished leaders of aviation from other countries and of which they can be justly proud. It gave him very real pleasure that they had been able to acquire their new headquarters during his year of Presidency. They hoped to make Hamilton Place the centre of aeronautical activity in this

country, a centre to which all engaged in our great industry will come for information, for study, for discussion, and for those social amenities which are a necessary part of any well ordered community.

The Council have been handicapped for many years and prevented from carrying out what obviously should be the work of the Society, by lack of the necessary funds. Thanks, however, to the generosity of many leading members of the Society the Council are now able to begin to plan ahead.

One of the major functions of the Society is to advise on and guide, as far as possible, the training of aircraft engineers. The Education Committee has been sitting over a long period considering the present examinations of the Society and a new syllabus. On a wider scale the Society has been represented on a Committee of the Society of British Aircraft Constructors to consider the training of aircraft apprentices along national lines. The Council have had under consideration the engineering degree examinations at the Universities and are pressing for a greater recognition of aircraft engineering by the Universities. He was happy only recently to lead a deputation from the Society to the University of London on this subject and he had every hope that their request for an engineering degree would be granted.

On the Agenda there appears the item " To consider Membership and Associate Membership." The Council have often felt that there are too many grades in the Society, more grades, indeed, than in any other corresponding Society. The grades of Membership and Associate Membership were introduced in 1927, following the amalgamation with the Institution of Aeronautical Engineers. Many old members of the Institution have recently suggested to the Council that the time has now come to review the position. The suggestion has been made that the two grades should be merged into those of Fellowship and Associate Fellowship respectively. This meeting gives members an opportunity to express their views upon the suggestion.

There was another and more important aspect of this question to which he drew their most earnest attention. The Council have been very conscious for some time that under the present rules for Fellowship and Associate Fellowship many leading men of wide experience and knowledge in the industry are unable to join the Society because they have not the necessary academic qualifications called for by the present rules. The Council at their last meeting were of the opinion that the rules for Associate Fellowship should be extended so that such men could be admitted, under proper safeguards, so that the status of the Society should not be lowered.

3. The Secretary read the Report of the Scrutineers of the ballot for Council for the years 1939-1941 and the President declared elected the following:—

Captain P. D. Acland, Companion.
Mr. D. L. Ellis, B.Sc., A.R.T.C., Associate Fellow.
Captain F. T. Hill, Fellow.
Air Vice-Marshal R. M. Hill, M.C., A.F.C., Fellow.
Lieut.-Col. W. Lockwood Marsh, LL.B., A.F.I.Ae.S., M.I.A.E., Fellow.
Lieut.-Col. J. T. C. Moore-Brabazon, M.C., M.P., Fellow.
Major B. W. Shilson, O.B.E., M.I.Mech.E., M.I.A.E., Fellow.
Mr. F. M. Thomas, Associate Fellow.
Dr. H. C. Watts, M.B.E., M.Inst.C.E., Fellow.
Mr. R. T. Youngman, B.Sc., Fellow.

4. Mr. Griffith Brewer proposed and Mr. L. A. Wingfield seconded that Messrs. Price, Waterhouse and Company be re-elected auditors for the ensuing year for Aerial Science, Limited, and Aeronautical Trusts, Limited.

The resolution was carried unanimously.

5. A discussion followed on the Membership and Associate Membership and Associate Fellowship proposals:—

Major B. W. SHILSON: Would the new proposals mean any considerable financial loss to the Society?

The PRESIDENT: The loss would be only some £25 a year.

Mr. MARCUS LANGLEY: He desired to put forward the point of view of one who was an original Associate Member of the Institution of Aeronautical Engineers before the amalgamation. He had felt at that time, as most of the Members and Associate Members did, that he wished to retain his grade. The position had altered since then, but if one looked back on the amalgamation one realised that it had been wholly successful, it had led to an improvement in the facilities of the joint body, both for the old members who came in at the time of the amalgamation and for the new members who had joined since, it had resulted in a reduction of overhead charges, and an increase of the Library, the libraries of the two bodies being thrown into one. What was the position as they found it now with regard to grading? They had Members and Fellows of equal status, meaning very nearly the same thing. They had Associate Fellows and Associate Members again of equal status, taking almost the same examination and meaning the same thing. He had failed to discover by what means the Grading Committee sorted applicants out into Associate Fellows and Associate Members. He had been a member of the Examinations Committee of the Society for many years, and he knew the difference in the examinations as between the two classes was so subtle as almost to defy distinction. It was all a question of the survival of a tradition, a tradition which members of the old Institution felt had practical rather than an academic meaning, but now if one looked over the lists of Associate Fellows and Associate Members one found them so mixed up that it was impossible to discover any line of demarcation. One found among the Associate Fellows both academic people and also practical designers. For his own part he saw no useful purpose in the continuation of that tradition. The work of the Society could go ahead just as easily if the two grades were run together, and they might be called by whatever name the Council chose, whether Fellows and Associate Fellows or Members and Associate Members.

He put forward the following resolution:—

> "That this meeting recommends the Council to consider the abolition of the grades of Membership and Associate Membership, and the transference of the existing members in those grades to the Fellowship and Associate Fellowship respectively."

Squadron Leader COLE seconded and the proposition was carried with one dissentient.

The PRESIDENT: The recommendation will go to the Council for consideration and action.

Under "Any Other Business," the President said that the Council was particularly anxious to have the advice and help of members as to how to increase the membership. The Council was determined to bring into the Society a greater proportion of technically trained engineers engaged in aviation. It was hoped that by having the new home of the Society in Hamilton Place, and by the International Conference which was proposed for the year after next, two great steps would be taken to bring in new members.

The SECRETARY: There was one type of engineer who was not catered for, and it would help the Council if they had some guidance as to the way in which he might be approached. He meant the production engineer. It was true that there was an Institution of Production Engineers to which such people could go, but at the same time they were doing largely aircraft work and they had not got a definite position as such at the moment. Naturally, one did not want to make a further grade of membership. The council had discussed the matter, but had not come to any conclusion, and it was rather hoped that some suggestion as to an enlargement of the membership might arise from the present discussion.

Mr. ROXBEE COX: He was glad that the Secretary had raised this point because there was still another class of man who would be of great benefit to the Society and who at the moment found it difficult to get elected. This was the type of man, who, for many years of his life, had been engaged in practical aeronautical engineering, but, probably through misfortune in his early days, had not been able to take a University degree or even to study for the Associate Fellowship Examination. There were a number of such people who would be very worthy Associate Fellows, and he for one would be glad to see some means of admitting these men into the Society's ranks. He had particular knowledge of several of them, and he had formed a general opinion that if they had attained a certain age and were able to produce duly authenticated evidence of their ability in their work, and if their application was supported by probably four or even more Fellows of the Society, they should receive the very serious consideration of the Council, independently of their ability to pass the Society's examinations.

He would also suggest that the present opening that such people had of getting in by means of a thesis should in such cases as he had described be waived. If the President desired him to make a definite proposal he was prepared to suggest very roughly the terms on which such people should be admitted.

Lieut.-Col. S. HECKSTALL-SMITH: He supported the last speaker. He could go back to 1911, and he had known from personal experience of men who had been foremen, assistant foremen, works' managers, and production engineers, who would be of extreme value to the Society. They might not be able to take degrees, but they were undoubtedly valuable people in the aeronautical world and it would be of enormous advantage to the Society to have them in. It could safely be left to the Council to decide on the experience and merits of each individual, having in view also the position he might hold, and to decide whether the necessary qualifications were forthcoming. Certainly such people should be welcomed at their meetings. The scientific man could always learn from the practical man.

Dr. N. A. V. PIERCY: He supported wholeheartedly the remarks of the last two speakers. He thought the men under consideration would be of great value to the Society and deserved being admitted, at the discretion of the Council as Associate Fellows.

Major SHILSON: Would these people not come in as Associates under Rule 35: "He shall have held a position equivalent to that of foreman in an aeronautical works for a period of not less than three years."

Mr. W. C. DEVEREUX: The Society was right in desiring to bring in these people. He did not think they should be considered under the present grade of Associate. The men who, by their proved eminence in the industry, had had ten years or more in the industry, and were of sufficient age, say 40, came within the class to which Mr. Roxbee Cox had referred, would add lustre to the Society.

Mr. FISCHELES: He would like to refer to the value of a statement as to membership of the Society in advertising situations. In Air Ministry advertisements he had not seen membership of the Society mentioned as an alternative in the same way as membership of the Institutions of Civil, Electrical, or Mechanical Engineers. It would encourage many people to join the Society if something were done in this respect.

The SECRETARY: That matter was under the consideration of the Council. It had its difficulties, but he had already spoken to one or two people at the Air Ministry about it, and their Past-President, Mr. Wimperis, Director of Scientific Research, and others were very sympathetic. The difficulty was to get the machinery, but he thought it could be done by the Council writing to the Air Ministry and asking for this to be officially put forward as in the case of other societies. The whole matter depended very much on the Society itself choosing the right men under the right conditions, as their own Society was doing at the present moment. A few years ago they got the Air Ministry to issue in the

Official Orders that if certain people had passed the Ministry's tests and taken certain papers they would be exempted from the Society's examinations, and that had had a great and beneficial effect. But these things had to be taken step by step. In practice when a man applied for a position as a technical officer at the Air Ministry, one of the first questions often asked him was, "Are you an Associate Fellow of the Royal Aeronautical Society?" That did weigh with the Air Ministry in making the appointment.

Mr. ROXBEE COX: He had drafted his proposal roughly in the following form:—

> "That this Annual General Meeting recommends to the Council that they should consider admitting to the Associate Fellowship a man who has had at least fifteen years' experience in aeronautics, is more than forty years of age, and has a record of distinguished service, provided his nomination is supported by four Fellows of the Society and, further, that his application shall be considered directly by the Council of the Society whose decision shall be final."

Lieut.-Col. HECKSTALL-SMITH seconded. He thought the requirement as to age limit and length of experience might be left a little fluid. The Council would naturally consider very carefully whether those were the figures which were the most suitable. There might be some very exceptional men who were a little younger than 40. He thought the requirement as to fifteen years' experience was reasonable. He was prepared to leave the matter in the hands of the Council.

Mr. M. LANGLEY: He moved an amendment that this matter be deferred until such time as the previous motion regarding the grades of Membership and Associate Membership had been considered by the Council.

The PRESIDENT: He thought that was rather splitting hairs. As the Council was intending to deal with the other matter within the next month, it would be rather wasting time to defer the decision on the matter now brought forward. He asked the meeting to vote on the proposal made by Mr. Roxbee Cox, which he thought was a most excellent one.

The motion was then put and carried unanimously.

This concluded the business of the Annual General Meeting.

SPECIAL GENERAL MEETING.

A Special General Meeting, under Rule 108, of the Royal Aeronautical Society was held on Wednesday, March 29th, 1939, in the Hall of the Institution of Mechanical Engineers.

In the chair: Mr. A. H. R. Fedden, M.B.E., F.R.Ae.S., President of the Society.

Present: L. R. E. Appleton (Graduate), B. D. Austen (Associate Member), W. E. Baptist, M.Inst.B.E., M.S.A.E., M.I.Ae.S., A.M.I.E.I. (Associate), Griffith Brewer (Honorary Fellow) (Vice-President), S. Camm (Fellow), Squadron Leader S. N. Cole (Associate Fellow), H. Roxbee Cox, Ph.D., D.I.C., B.Sc. (Fellow), W. C. Devereux (Fellow), C. Robson Elgie (Associate), G. A. G. Embleton (Companion), E. G. Fischeles (Associate Fellow), Squadron Leader H. P. Fraser (Associate Fellow), A. Gouge (Fellow), R. C. B. Hendy (Associate Member), Professor F. T. Hill (Fellow), M. Langley (Member), R. L. Lickley, B.Sc., D.I.C. (Associate Fellow), P. G. Masefield, M.A. (Student), N. A. V. Piercy, M.I.Mech.E., D.Sc., A.M.Inst.C.E. (Fellow), Professor A. J. Sutton Pippard, M.B.E., D.Sc., M.I.C.E. (Fellow), C. P. Plantin, B.Sc. (Graduate), B. Shenstone (Associate Fellow), Major B. W. Shilson, O.B.E., M.I.Mech.E. (Fellow), Lieut.-Col. S. Heckstall-Smith (Fellow), C. D. Stanley, A.M.I.E.E. (Companion), D. Stevenson (Associate Fellow), P. C. Thornton (Associate Fellow), L. Wingfield, M.C., D.F.C. (Associate).

Capt. J. Laurence Pritchard (Secretary) in attendance.

The Secretary read the notice convening the meeting.

The SECRETARY: The first business was to consider proposals put forward by the Council for alterations of the Rules. It was proposed to raise the period of experience required of Associate Fellows from three to five years. The Council wished to make it clear that as far as Students and Graduates who were elected before these new Rules had been passed, they would come under the old three-year rule.

The PRESIDENT: This matter had been considered very carefully by the Council and also by the Grading Committee.

Mr. FISCHELES: Would the five years' requirement apply to all students who graduated whether from a University or from a day college?

The SECRETARY: It did not matter what the training was. The proposal applied to all applicants for Associate Fellowship, with the exception of Students and Graduates now on the rolls who joined the Society after the date to be fixed. They were required to have five years' experience in aviation instead of three.

Major B. W. SHILSON then formally proposed:—

> "That in Rules 19 (*b*), 20 (*b*) and 25, the word 'three' should be altered to 'five' in every case where it appears in these Rules, the effect of the alteration being to increase the experience required for Associate Fellowship and Associate Membership from three to five years."

Mr. W. C. DEVEREUX seconded, and the resolution was carried with two dissentients.

The SECRETARY: The second matter was to consider a proposal that the present scale of compounding subscriptions should apply to members compounding within the first five years of joining, and that the amount should be reduced by one guinea per annum for each year of membership after five years. This involved an alteration in the Appendix "Subscriptions" of the Rules. At the present time, if a member wanted to compound the sum required of him varied from twelve to fifteen years' annual subscription payments. The new proposal was that a member whose membership had extended for five years or more could reduce the sum by one guinea for each year of membership. For example, an Associate Fellow paid an annual subscription of three guineas a year. He could compound for life by paying 45 guineas. If he had been a member for ten years and wanted to compound, he had five guineas knocked off that sum, and paid forty guineas only.

The PRESIDENT: This was a standard procedure in other Societies. It might be that at the moment a man was in a fairly remunerative job and could afford to compound, and perhaps at a later date he might not be so fortunately situated.

Professor PIPPARD: Would this be retrospective?

The SECRETARY: As a general rule these arrangements were not retrospective, but he supposed that any member at the present time who wanted to compound would come within that Rule.

Mr. W. C. DEVEREUX: Was it correct that if a member had been in the Society for fifteen years he could compound on a fifteen years' basis?

The SECRETARY: That was the case—he had ten years knocked off.

Mr. ROXBEE COX: Is it clear what happened if after compounding for the Associate Fellowship a man was elected to Fellowship?

The SECRETARY: In that case he would pay the difference. That had always happened when a man was elected, for example, from Associate Fellow to Fellow. The amount he had paid as Associate Fellow was credited to his Fellowship subscription.

Professor PIPPARD: He proposed that the Council's proposal be accepted.

Mr. ROXBEE COX seconded.

The resolution was carried, and the business of the Special General Meeting terminated.

PRESIDENT.

At the May meeting of Council, Mr. A. H. R. Fedden, M.B.E., D.Sc., M.I.A.E., M.I.Mech.E., M.S.A.E., F.R.Ae.S., President of the Society, was elected for a second year of office from October, 1939, to September, 1940.

VICE-PRESIDENTS.

At the May meeting of Council, Mr. Griffith Brewer, Hon. F.R.Ae.S., Vice-President of the Society, was elected for a second year of office from October, 1939, to September, 1940, and Air Vice-Marshal R. M. Hill, M.C., A.F.C., M.A., F.R.Ae.S., was elected a Vice-President for the same period.

MEDALS AND AWARDS.

The following awards have been made by the Council:—

Silver Medal.

To Major R. H. Mayo, O.B.E., M.A., Assoc.M.Inst.C.E., F.R.Ae.S., for his work leading to an advancement in aeronautical design.

The Silver Medal is awarded annually, at the discretion of the Council for some advance in aeronautical design.

Taylor Gold Medal.

To Squadron Leader H. P. Fraser, A.F.C., B.A., A.F.R.Ae.S., R.A.F., for his paper on "High Wing Loading and Some of its Problems from the Pilot's Point of View."

The Taylor Gold Medal is awarded annually, at the discretion of the Council, for the most valuable paper submitted or read during the previous session.

Wakefield Gold Medal.

To Mr. Leslie L. Irvin for his work on parachute design which has led towards safety in flying.

The Wakefield Gold Medal is awarded annually to the designer of any invention or apparatus tending towards safety in flying.

Busk Memorial Prize.

To Squadron Leader G. M. Buxton, R.A.F., for his paper on "The Development of Sailplanes," and to Mr. H. F. Vessey, A.F.R.Ae.S., for his paper on "Effect of Wing Loading on the Design of Modern Aircraft with Particular Regard to Take-off Problems."

The Edward Busk Memorial Prize is offered annually for the best paper received by the Society on some subject of a technical nature in connection with aeroplanes or seaplanes.

Pilcher Memorial Prize.

To Mr. H. E. J. Rochefort, Wh. Sch., A.C.G.I., D.I.C., for his paper on "The Theory and Practice of Stressed Skin Construction for Aeroplanes."

The Pilcher Memorial Prize is offered annually for the best paper by a student on heavier-than-air craft or any analogous subject.

Usborne Memorial Prize.

To Mr. P. H. Rayner, B.Sc., for his paper on "Notes on Aero Engine Research."

Awarded annually for the best paper by a Student on aero engines.

MAJOR BADEN-POWELL MEMORIAL PRIZE.

The Major Baden-Powell Memorial Prize for the student who is considered best by the examiners in the Associate Fellowship and Associate Membership Examinations has been awarded to E. T. B. Smith on the results of the May, 1939, examinations, and to Mr. D. I. Vickery on the results of the December, 1939, examinations.

ELLIOTT MEMORIAL PRIZE.

The Elliott Memorial Prize has been awarded to Leading Aircraft Apprentice Nash, L.R., and Aircraft Apprentice Brooks, C.L., of Halton. The Elliott Memorial Prize, administered by the Society, is awarded twice yearly to the apprentice at Halton who has the highest percentage of marks in the passing-out examination.

HONOURS.

The following members were the recipients of Honours during the year :—

Knight Bachelor.—W. Lindsay Everard, M.P. (Companion).

Air Force Cross.—Squadron Leader J. F. X. McKenna (Associate Fellow).
Squadron Leader G. Silyn-Roberts (Associate Fellow).
Flight Lieut. C. A. Pike (Associate Fellow).

SOCIETY OF BRITISH AIRCRAFT CONSTRUCTORS' SCHOLARSHIPS.

The Scholarships Selection Committee of the Society of British Aircraft Constructors and the Royal Aeronautical Society made awards of S.B.A.C. Scholarships to the following :—

Frank Ashton, 5, Back Street, Chorley, Lancs.
Peter Reyner Banham, 25, Larkman Lane, Norwich.
Gabriel Lancaster, 6, Dunlop Avenue, Lenton Boulevard, Notts.
Denis Moore, 129, Victory Avenue, Paddock, Huddersfield.
Geoffrey Westwood, " Glenmay," Amblecote Road, Quarry Bank, Staffs.
Raymond Wilks, 5, Jubilee Crescent, Killamarsh, Sheffield.

WILBUR WRIGHT MEMORIAL LECTURE.

The 27th Wilbur Wright Memorial Lecture was delivered by Dr. G. W. Lewis, F.I.Ae.S., on " Some Modern Methods of Research in the Problems of Flight," and a full report was published in the October, 1939, Journal.

LECTURE PROGRAMME.

The following lectures were arranged for the second half of the 1938-1939 Session :—

Jan. 5th.—" The Use of Model Data in Aeroplane Design," Miss F. B. Bradfield, M.A., A.F.R.Ae.S., and Mr. D. L. Ellis, B.Sc., A.R.T.C., A.F.R.Ae.S.

Jan. 19th.—" Some Corrosion Problems Relating to Modern Aircraft," Mr. A. J. Sidery, A.F.R.Ae.S., and Mr. J. W. W. Willstrop, B.Sc., A.I.C.

Feb. 7th.—" Sleeve-Valve Engines," Mr. A. H. R. Fedden, M.B.E., D.Sc., M.I.A.E., M.S.A.E., F.R.Ae.S., Joint Lecture with the Institution of Automobile Engineers.

Feb. 16th.—" Ignition Problems," Dr. G. E. Bairsto, M.I.E.E., F.Inst.P.

March 2nd.—" Testing Stability and Control of Aeroplanes," Dr. A. G. von Baumhauer.

March 16th.—" Review of the Relative Merits of Carburettors and Direct Petrol Injection for Aero Engines," Mr. J. E. Ellor, F.R.Ae.S., and Mr. F. M. Owner, F.R.Ae.S.

March 30th.—" The Problem of Ancillary Power Services on Aircraft," Mr. F. Nixon, B.Sc., A.F.R.Ae.S., and Mr. R. H. Chaplin, B.Sc., A.F.R.Ae.S.

April 20th.—" Possible Steel Developments for Aircraft," Dr. T. Swinden, F.R.Ae.S.

May 4th.—" Strength of Thin Metal Construction," Mr. H. L. Cox.

BRANCHES.

The following is a list of Branches:—

Australian.

Hon. Sec.: J. B. Mills, B.Sc., Science House, Gloucester and Essex Streets, Sydney, Australia.

Belfast.

Hon. Sec.: W. H. Hambrook, A.F.R.Ae.S., Short and Harland, Limited, Queen's Island, Belfast.

Bristol.

Hon. Sec.: S. G. Nash, A.F.R.Ae.S., Whyteleafe, 4, Kenmore Grove, Filton Park, Bristol, 7.

Brough.

Hon. Sec.: S. J. Smyth, A.F.R.Ae.S., Blackburn Aircraft, Limited, Brough, East Yorks.

Cambridge University Engineering and Aeronautical Society (affiliated to the Royal Aeronautical Society).

Sec.: J. G. Lubbock, Trinity College.

Coventry.

Hon. Sec.: J. A. Beardsall, Stud.R.Ae.S., c/o Armstrong-Whitworth Aircraft, Ltd., Whitley, Coventry.

Gloucester and Cheltenham.

Hon. Sec.: F. B. Ford, A.F.R.Ae.S., St. Margaret, Brockworth, Nr. Gloucester.

Hatfield.

Hon. Sec.: H. W. L. Calder, A.R.Ae.S., de Havilland Aircraft Company, Limited, Hatfield, Hertfordshire.

Isle of Wight.

Hon. Sec.: M. J. Brennan, A.F.R.Ae.S., c/o Technical Office, Saunders-Roe, Ltd., Cowes.

Manchester.

Hon. Sec.: J. E. A. Waterfall, 56, Manor Avenue, Ashton-on-Mersey, Cheshire.

Medway.

Hon. Sec.: J. W. Loader, A.F.R.Ae.S., 174, City Way, Rochester.

Montreal Aeronautical Section.

Address: Engineering Institute of Canada, 2050, Mansfield Street, Montreal, Canada.

Ottawa Aeronautical Section.

Hon. Sec.: M. S. Kuhring, A.R.Ae.S., National Research Council, Aeronautical Laboratory, Ottawa, Canada.

Portsmouth.

Hon. Sec.: J. F. Foss, Airspeed (1934) Limited, The Airport, Portsmouth, Hants.

Southampton.

Hon. Sec.: T. Tanner, A.C.G.I., D.I.C., A.F.R.Ae.S., 1, The Retreat, Southsea, Hants.

Weybridge.

Hon. Sec.: D. L. Ellis, A.F.R.Ae.S., Vickers Limited, Weybridge, Surrey.

Yeovil.

Hon. Sec: Flt.-Lt. G. N. Snarey, A.F.C., A.R.Ae.S., R.A.F.O., Westland Aircraft Works, Yeovil, Somerset.

BRANCH LECTURES.

Belfast Branch.

Tuesday, Feb. 7th.—Lecture by Mr. J. Lankester Parker, A.F.R.Ae.S., on "Testing Prototype Aircraft."

Tuesday, March 14th.—Mr. J. G. Hopcraft, M.C., A.M.I.Ae.E., Film on Steelmaking with commentary.

Coventry Branch.

Wednesday, Jan. 4th.—Visit to Coventry Gauge and Tool Company, at 7.0 p.m.

Thursday, Jan. 19th.—Lecture by Mr. E. W. Knott on "Carburation as Applied to Modern Aircraft Engines," at 8.15 p.m.

Thursday, Feb. 16th.—Exhibition of Instructional Talkie Films, introduced by Wing Commander H. Nelson, Air Ministry.

Thursday, March 16th.—"Automatic Control for Aircraft," by G. W. H. Gardner, R.A.E., Farnborough.

Thursday, April 20th.—"Model Flying," by Howard Boys.

Visits. Saturday, Jan. 28th.—Rolls-Royce, Ltd., Derby.
Saturday, June 10th.—National Physical Laboratory.

Hatfield Branch.

Wednesday, April 25th.—Lecture by Dr. Roxbee Cox, F.R.Ae.S., on "The Future Development of Aircraft Construction."

Isle of Wight.

Tuesday, Jan. 10th.—Lecture by H. Mason Garner, M.A., F.R.Ae.S., on "Research on Seaplanes."

Tuesday, Jan. 31st.—Lecture by R. Worsdale on "Manufacture of Light Alloys."

Tuesday, Feb. 14th.—Lecture by Sir A. Verdon-Roe, Kt., O.B.E., M.I.Ae.E., F.R.Ae.S., on "Past, Present and Future in Aviation."

Tuesday, Feb. 28th.—Lecture by Mr. J. Hopcraft, on "Manufacture of Steel Alloys."

Tuesday, March 14th.—Debate.

Manchester Branch.

Thursday, Feb. 9th.—Film on Steel Making, by J. G. Hopcraft.

Thursday, March 9th.—Lecture by Captain A. S. Wilcockson on "North Atlantic Flights."

Medway Branch.

Monday, Jan. 9th. Lecture by Mr. W. C. Devereux, F.R.Ae.S., on "Light Alloys."

Monday, Feb. 6th.—Lecture by Mr. G. Parkin, B.Sc., A.M.I.A.E., A.F.R.Ae.S., on "Constructional Features of the Merlin Engine."

Monday, March 6th.—Lecture by Captain A. S. Wilcockson, on "Atlantic Air Routes."

Portsmouth Branch.

Thursday, Jan. 12th.—Lecture by Mr. B. S. Shenstone, A.F.R.Ae.S., on "Recent Progress in German Aircraft."

Thursday, Jan. 26th.—Lecture by Mr. D. L. Ellis, B.Sc., A.R.T.C., A.F.R.Ae.S., on "The Wind Tunnel as an Aid to Aircraft Design."

Thursday, Feb. 9th.—Lecture by Captain A. S. Wilcockson, O.B.E., on "Atlantic Crossings by Empire Boat."

Thursday, Feb. 16th.—Lecture by Mr. W. Hackett on "Modern Developments in Steel Tubes for Aircraft."

Thursday, Feb. 23rd.—Lecture by Mr. F. C. Lynam, A.F.R.Ae.S., A.F.I.Ae.S., on "Variable Pitch Airscrews."

Thursday, March 9th.—Lecture by Mr. G. Dring, B.Sc., M.A., F.I.C., on "Plastics."

Thursday, March 16th.—Lecture by Mr. M. B. Morgan, B.A., on "Flying Controls."

Thursday, March 23rd.—Lecture by Dr. H. Roxbee Cox, Ph.D., D.I.C., B.Sc., F.R.Ae.S., on " Future Development of Aircraft Construction."

Southampton Branch.

Wednesday, Feb. 1st.—Lecture by Mr. C. G. James on " The Metallurgy of Aircraft Materials."

Wednesday, March 1st.—Lecture by Mr. D. Hollis Williams, B.Sc., F.R.Ae.S., on " The Tricycle Chassis."

April 5th.—Lecture by Mr. M. S. Hooper, F.R.Ae.S., on " The Sailing Yacht in Comparison with the Aeroplane."

Weybridge Branch.

Wednesday, Feb. 22nd.—Lecture by Squadron Leader H. P. Fraser, A.F.R.Ae.S., on " Aircraft Controls from the Pilot's Viewpoint."

Wednesday, March 22nd.—Lecture by Mr. N. S. Muir, B.Sc., A.F.R.Ae.S., on " Some Aspects of Flight Testing of Engines."

Wednesday, April 12th.—Lecture by Mr. G. H. Miles, D.Sc., on " The Human Factor in Production."

Yeovil Branch.

Thursday, Jan. 12th.—Lecture by Mr. R. H. Bound, A.F.R.Ae.S., on " Retractable Undercarriages."

Thursday, Feb. 2nd.—Lecture by Mr. John Hopcraft, A.M.I.Ae.E., on " Steel Manufacture."

Thursday, March 2nd.—Lecture by Mr. F. W. Burnard on " Lysander in India."

GRADUATES' AND STUDENTS' SECTION.

The following summarises the activities of the Graduates' and Students' Section for 1939:—

Officers for 1939.

Chairman: Mr. P. G. Masefield, B.A. (Eng.).

Vice-Chairman: Mr. R. B. Wilkinson.

Honorary Secretary: Mr. W. Tye, B.Sc. (Eng.).

MEETINGS AND VISITS.

1939.

Jan. 10th (Tuesday).—" Flying for Fun." By Mr. F. D. Bradbrooke. Chairman: Mr. E. Colston Shepherd.

Jan. 21st (Saturday).—Visit to de Havilland Aircraft Co., Stag Lane; Engines and Airscrew Departments. Time: 2.30 p.m. (Limited to 30 British subjects.)

Jan. 31st (Tuesday).—" Influence of Airscrews on Engine Design." By Mr. F. M. Thomas, A.F.R.Ae.S.

Feb. 7th (Tuesday).—" Ignition." By Mr. F. R. F. Ramsay. Chairman: Lieut.-Col. L. F. R. Fell, D.S.O., O.B.E.

Feb. 21st (Tuesday).—" Duct Design." By Mr. G. N. Patterson, Ph.D., A.F.R.Ae.S. Chairman: Mr. W. G. A. Perring, R.N.C., A.F.R.Ae.S.

March 7th (Tuesday).—" Plastics." By Mr. M. Langley, A.M.Inst.N.A., M.I.Ae.E.

March 18th (Saturday).—Visit to the New Wind Tunnel and Testing Laboratory, Fairey Aviation Company, Limited, Hayes, Middlesex. Time: 2.30 p.m.

March 21st (Tuesday).—" The Limitation of Aircraft Speeds by Compressibility." By Mr. W. F. Hilton, Ph.D., D.I.C., A.F.R.Ae.S. Chairman: Mr. E. F. Relf, F.R.S., F.R.Ae.S.

April 11th (Tuesday).—" The Status of the Aeronautical Engineer." Discussion opened by Mr. J. V. Connolly, B.E., A.F.R.Ae.S. Chairman: Mr. A. H. R. Fedden, M.B.E., F.R.Ae.S. (President).

ASSOCIATE FELLOWSHIP AND ASSOCIATE MEMBERSHIP EXAMINATIONS, 1939.

The following candidates were successful at the examinations held in May, 1939:—

ASSOCIATE FELLOWSHIP.

J. A. Channer	Aerodynamics. Pure Mathematics.
R. Clemens	Design (Aircraft) (First Place).
D. A. Clifton-Mogg ...	Strength of Aeronautical Materials and Structures.
P. L. Cronbach	Strength of Aeronautical Materials and Structures (First Place). Aerodynamics. Pure Mathematics.
H. Donovan	Pure Mathematics.
N. F. Downes	Design (Aircraft). Applied Mathematics.
S. Holman	Strength of Aeronautical Materials and Structures. Pure Mathematics.
P. K. Hunt	Pure Mathematics (First Place).
D. C. Jenkins	Strength of Aeronautical Materials and Structures. Aerodynamics (First Place). Design (Aircraft). Applied Mathematics.
J. Lansdell	Design (Aero Engines). Pure Mathematics.
P. de L. Markham ...	Applied Mathematics (First Place).
J. F. M. Oram	Design (Aircraft).
I. H. Ring	Strength of Aeronautical Materials and Structures. Design (Aircraft). Pure Mathematics.
J. Saoula	Air Transport.
A. G. Shove	Design (Aircraft). Applied Mathematics.
R. C. Sowerbutts ...	Design (Aircraft).
C. R. Tennant	Design (Aircraft).
D. E. Thackeray	Design (Aero Engines) (First Place).

ASSOCIATE MEMBERSHIP.

E. T. Smith	Pure Mathematics (First Place). Theory of Internal Combustion Engines (First Place). Design (Aero Engines) (First Place).
R. T. Weatherstone ...	Pure Mathematics.

The following candidates were successful in the December, 1939, examinations:

J. W. A. Andrews	Design (Aero Engines). Theory of Internal Combustion Engines. Applied Mathematics.
R. Clemens	Applied Mathematics.
H. F. O. Dawes	Strength of Aeronautical Materials and Structures. Aircraft Materials (First Place).

R. B. Dickenson	Design (Aero Engines). Theory of Internal Combustion Engines. Applied Mathematics.
H. Donovan	Aircraft Instruments (First Place). Aerodynamics (First Place).
N. F. Downes	Strength of Aeronautical Materials and Structures.
E. G. Dunsford	Aircraft Instruments. Theory of Machines.
B. St. John Emery	Design (Aero Engines). Theory of Internal Combustion Engines (First Place). Applied Mathematics.
N. Geen	Design (Aero Engines). Theory of Internal Combustion Engines. Applied Mathematics.
L. S. Greenland	Applied Mathematics.
H. M. Hackett	Design (Aero Engines). Theory of Internal Combustion Engines. Applied Mathematics.
R. W. J. Horsley	Theory of Internal Combustion Engines. Design (Aircraft).
A. G. Kemp	Aircraft Instruments.
D. M. McElhinney	Design (Aircraft). Pure Mathematics.
P. McGinn	Theory of Internal Combustion Engines.
C. F. Onions	Design (Aero Engines) (First Place). Theory of Internal Combustion Engines. Pure Mathematics.
T. B. O'Reilly	Strength of Aeronautical Materials and Structures.
W. H. Paine	Strength of Aeronautical Materials and Structures. Aerodynamics. Pure Mathematics.
E. C. W. Pearce	Design (Aero Engines). Theory of Internal Combustion Engines. Applied Mathematics.
J. A. Ross	Design (Aero Engines). Applied Mathematics.
F. E. Sahyoun	Theory of Internal Combustion Engines.
F. Shroff	Design (Aero Engines). Theory of Internal Combustion Engines. Applied Mathematics.
J. A. Tickner	Design (Aero Engines).
D. I. Vickery	Strength of Aeronautical Materials and Structures (First Place). Design (Aircraft) (First Place). Pure Mathematics (First Place).
F. V. Walker	Aircraft Materials.
E. J. Weiss	Design (Aircraft).
J. A. Withnell	Design (Aero Engines). Theory of Internal Combustion Engines. Applied Mathematics.

MEMBERS ELECTED DURING 1939.

The following members have been elected since the last report:—

On January 18th, 1939:—

Fellows.—Herbert John Thomas, Horace Myers.

Associate Fellows.—William Henderson Coulthard (from Student), Thomas Leslie Garner, Harry Owen Houchen, Louis Alexander George Howard (from Student), James William Kenny (from Student), Godfrey Henry Lee (from Student), Victor Hubert Leech, Edward William Lofts (from Student), Peter Reginald Poole (from Student), Frank Holmes Smith (from Student), Warren Utley Snell, Eric Raymond Staniland, Ralph Francis Newman Swingler (from Student), Kenneth Jack Blackler Wolfe.

Associate Member.—John Henry Fulford.

Associates.—Miss Nancy Bird, Paul Howlett Campion, Cawas Burjorji Contractor, George Norman Snarey.

Graduates.—George Albert Campbell, William Isbister, Clifford Leslie Moon, Thomas Robert Nelson, William Anthony Porter, Robert Neville Sjogren.

Students.—Edward Geoffrey Barnes, Douglas Thornton Brown, Ernest Charles Brown, Eric Byron, Leslie Samuel Carthew, D. M. Cashmore, Thomas Charlesworth, Dennis Harry Clarke, Ralph Henry Clifford, John Carol Collins, Eric Frank Cotton, George Cruickshank, James Henderson Deas, Harold B. Devereux, Kenneth Graham Furneaux, Thomas Kenneth Garrett, William Henry Noel Gibby, John Philip Golding, John Charles Oswald Grunert, Geoffrey James Barnard Hall, Charles John Hayne, Peter Davison Heuser, Denis Keogh Kempston, William Lauder McAllister, Herbert Ronald Marlow, Walter Herbert Mitchell, Henry Edward Monteith, Frederick William Pawsey, Albert George Reddy, Peter Richardson, Raymond Frederick Rowley, Roy Owen Roberts, Thomas Brabazon Rutherford, Percy Scott, Edward Sewell, Nelson Anthony Simpson, Bhupendra Singh, John Kelday Smith, Leon Edward Smith, James Alexander Stephen, John Frederick Story, John Blakemore Tayler, Roy Fenning Warren, Hugh Cecil Lovat White, Cyril Robert Wiggett, Ronald Winston Woolford.

On February 15th, 1939:—

Fellow.—Ernest Walter Hives.

Associate Fellows.—Cyril Oswald Blakemore, James Phipps Booth (from Student), Joseph Raphael Crean (from Companion), Harold Ralph Day, Laurence Field, Kenneth Bryan Gillmore (from Student), Albert Claude Kidney, Robert Kronfeld, Roy James Nixon, Joseph Andrew O'Brien, Arthur Parkes, Demetrius George Samaras (from Graduate), James Godwin Strong, Alexander William Torry, Patrick Newton Vincent, Arthur Sidney Wilcockson.

Associate Members.—George Hobbs, Eustace Cecil Joseph O'Hanlon, Charles Henry Sexton.

Associates.—John Aherne-Heron, Harold Brown, Herbert William Leslie Calder, Alan Arthur Edward Clutten, Reginald Ernest Collins, Walter Stanley Hollyhock, William Jackson, Herbert Edgar Lewis, Alfred Osborne, Allen Gerald Peters, William George Wainwright-Fahey, Rowland Wilkinson, Harry Wright.

Graduates.—Leslie William Andrews, John Hanway Parr Brymer, Alfred John Lawrance Collinson, Ferdinand Basil Greatrex, John

Leslie Hewitt, Frederick Alexander Nigel Hitch, Alexander Jardine (from Student), Eric Redgrave Owen (from Student).

Companions.—Beecher Boncroft Cary, Ivor William Jones, Henry William Masterton, Thomas McCowat, Philip Henry Riseley, F. Geoffrey Wayman.

Students.—John Elliston Allen, James Walter Agnezn Andrews, Nevil James Ashton, Ronald John Atkinson, Douglas Arthur Baker, Cecil Beardsley Baker, Richard Devon Bale, Frank Norman Bartlett Bennett, Alfred Peter Bond, Thomas Henry Cain, James Derek Evans, Eric Donald Govaars, Edward John Hidson, Shukry Kamel Ibrahim, Charles Henry Johns, John Glyn Jones, Horace Victor le Dieu, George Maurice Martin Magill, Hugh Eimai McCormick, Leo Anthony Mcquillan, Philip Evan Mitchell, Anthony Christopher Claude Packe, Ronald Ernest Penney, John Macgregor Lund Roberts, George Campbell Smith, Mieczyslaw Sokol, Ronald Wilfred Thomas, Donald Launcelot Turner, Hubert William van Rhyn, Geoffrey Verdon-Roe, Norman Stanley Watson, Joseph Yeates.

On March 15th, 1939:—

Honorary Fellow.—Lester Durand Gardner (formerly Associate Fellow).

Fellow.—John Dunbar Blyth (from Associate Fellow and is also a Member).

Associate Fellows.—Alfred William Barr, Raymond Noel Dorey, Reginald Ernest Gustine (from Associate), Robert Henry Travell Harper, Sylfanus Robert Lewis (from Student), Wynand Johannes Pretorius (from Student), William Eliezer Prytherch, Miss Grace Mary Bruce Quennell (from Student), Ernest William Still, Frederick William Wardley.

Associate Member.—George Henry Hull.

Associates.—Laurence Percival Burch, William Bertram Coles, William Russell Livingstone, George Arthur Grindell Morris.

Graduates.—Thomas Marcel Blanch, George Percy Jewell (from Student), Frank Marshall Reynolds.

Companions.—Syed Nagui Bilgrami, H. J. Wolffsohn.

Students.—Thomas Barrow. James Arthur Chamberlin, Walter Leonard Clarke, Arthur Wickman Coney, Frederick Cormack, Peter Linton Cronbach, Alfred Maurice ffoulkes, Gordon Fryer, Basil Jackson, David Sadler, John Henry Francis Scrope, Trevor Hetherington Tarr, Wilfred Kenneth Tedham, Stuart Spencer Wyllie, Wilfred Charles James Garrard.

On April 26th, 1939:—

Fellows.—Albert George Elliott, George Edward Petty (from Associate Fellow).

Associate Fellows.—George William Barber, Handel Davies (from Student), Maurice Larwood Gaine (from Associate), Harry Cecil Harrison, Harry Higgins (from Associate), John Hogan, George Leslie Keen, Kenneth Malise St. Claire Graeme Leask, Percy Hargrave Legg, William Perrin Lewis (from Associate), George Ashley Mann, Matthew Lee Murphy, William Charles Sharp, Alan Howard Stratford (from Student), Austin George Alan Tawell, John Edgeworth David Touche.

Associate Members.—James Diaper (from Student), Leslie Reginald Bloomfield Ford, Henry Hamilton Clifford Hester, Leonard Taylor.

Associates.—Henry Eccarius Bolton, Albert Edward York Bramble, Guy Thornton Walpole Champneys (from Student), Harold Cecil Comben, Bertram Cornthwaite (from Student), Gerald FitzGerald-Lee, Jag Nath Mathur, Anthony Cory Myers, Sydney Oldfield, Albert Edward Shepherd, James Hay Stevens (from Student), William Arthur Jevons Street (from Student).

Graduates.—Eric Raymond Arbon (from Student), Leslie Frederick Atkinson, Hubert William Jordan Brittlebank from Student), Elfyn John Richards (from Student).

Companion.—Edward Stephen Wilkins.

Students.—William Astley, James Arthur Beardsall, Richard Harold Botterill, Edward York Bramble, Edgar P. Bridgland, Dudley Ransford Hudson de Fonseka, William Leonard Howells, David Cumming Jennings, Clifford Henry Clive Jennings, William Taylor Kirkby, Ronald Sinclair Massey, Robert William Molyneux, Peter Fyfe Mouritz, George Herbert Palk, Richard Gabriel Robinson, David Moline Warner, Ian Neville Way, John Victor Price Williams.

On May 10th, 1939:—

Fellow.—Archibald Edward Russell (from Associate Fellow).

Associate Fellows.—Raleigh Willoughby Hilken, Walter Stanley Hollyhock (from Associate), Cecil Thomas Locke (from Student), Peter Gordon Masefield (from Student), Helmuth Albert Martin Sachse, Thomas Stevenson Smith, Alfred Lionel Woode.

Associates.—Frederick Anson Firth, William John Gessey, Frederick Pye, Eric Skelton, Frederick Henry Buller Sorrell, Winston Walker.

Students.—Roderick William Burn-Callander, William John Ewart Craigen, William Spooner Hemp, Antony Michael Hale Lewin, William Hugh Duncan McCorquodale, Peter John Thursby, Sydney William Wild.

Companions.—Mrs. Florence Mary Morris-Davies, Albert James Payne.

On June 14th, 1939:—

Fellows.—George Purves Douglas (from Associate Fellow), Arthur Veryan Stephens (from Associate Fellow).

Associate Fellows.—Ernest George Barber, John Raymond Bufton (from Student), Hal Cullen Darney, Charles Peter Graham Engelbach (from Student), Douglas James How (from Student), John Watson Leach (from Graduate), Arthur Henry Martin (from Student), John Kerr Reid, Jack William Roderick, Thomas George Ross, Denis Bonham Smith.

Associates.—Roland John Falk, Barton Stilwell Freeland, Maldon Cavendish Harley (from Companion), Henry Hollingdrake, Kenneth Charles Tecklenborough Marshall, Robert Wood Mackay, Robert Laurence Morrison, Herbert George Albert Newman, Eric Harry Oxley-Boyle, Harry Edgar William Robinson, Geoffrey Arthur Virley Tyson.

Companions.—Sidney Charles Davey, Frederick James Ellen, Victor Haefner, William Percival Hildred, Eric Lord, Edward Warburton Phillips.

Students.—Bertel Fredrik Andersin, Reginald Harrington Capp, George Dobson, Antony Martin Edwards, Denis White Little, Keith Robert Obee, Arthur Ernest Polden, Charles Frederick Toms, Marcus Nelthorpe Wilson.

On October 1st, 1939:—

Fellows.—Francis Thomas Hearle, Herbert Geoffrey Morcom, Edgar Alfred Allcut (from Associate Fellow), Arthur Joseph Hughes (from Associate Fellow), H. John Stieger (from Associate Fellow), Percy Brooksbank Walker (from Associate Fellow).

Associate Fellows.—Paul Emory Clift, Roland Claude Cross, Lancer Dudley Vibart Edwards, Philip Francis Everitt, Archibald Graham Forsyth, Robert Ernest Hardingham, Geoffrey Moffat Hellings, Benny Lockspeiser, Frank John Murdoch (from Companion), Arthur Drummond William Pimm (from Graduate), John Cecil Kelly Rogers, Edward Smyth, Stanley Joseph Smyth, Robert James Spearman (from Graduate).

Associates.—Graham Brook Bell, John William Sefton Brancker, John David Cunningham, Kenneth Moreton Frewin, John Burgoyne Joyce, Shashi Majmudar, Henry Campbell Russell, Howard Charles Sheath, Joseph Carey Crabtree Taylor.

Graduates.—Brian Hugh Muirhead Buck (from Student), John Owen Parker Dibbs, William Patrick Ingram Fillingham (from Student), John Hawke Horsfield (from Student), William James Muskett, Thomas Henry Redding, Philip George Richardson, Norman Wilfred Savage.

Students.—Arthur Lionel Benns, Harold Colin Black, John Morrison Boulter, Ronald French Carter, Ronald Arthur Cashel, Vivian James Chalwin, Peter Smithard Champion-Jones, James Alfred Collins, William George Coxon, Eric Crowe, Frank Cyril Dedman, Douglas Fernley Denbow, Joseph Raymond Dennis, Ronald Dimberline, Edward Reed Douglass, Harold Frederick Drummond, Arthur William Edwards, Stanley Charles Evans, Walter Fairey, Donald Albert Flint, Reginald Thomas Folley, Douglas Foster, Darrell Ivor Gale, Trevor Douglas Buchanan Garrett, Edmund Frank John Gericke, Alfred Kenneth Germain, John Ernest Haines, William Henry Harris, William Ronald Hasler, William Samuel Haynes, William Norman Helsby, Robert Walter Hern, Dennis Hill, Ronald Frank Hitchcock, James Inward, Henry Alfred Jackman, Peter Edward James Jenkins, Eric John Jennings, Norman G. Jones, Oliver Keene, William Alfred Clifford Kendall, James Henry Kent, Ronald Lasslett-Carter, Julian Leslie, Kelvin Oliver Lockyear, Michael John McCluskey, John Frederick McGowan, Joseph Mackereth, Cyril Roy Major, Reginald Wilfred Manning, Gerald James Matthews, John Meaking, John Edward Millis, Robert John Millson, Edward Frank Mitchell, Patrick James Moore, Richard Ronald Moore, John Blair Willis Murray, Leslie Raymond Nash, Arthur Cyril Needham, Bruce Allan Noble, Denys Norton, Arthur William Nunn, Ian Bruce Ogilvie, Edward Harold Orchard, Norman Leslie Cyril Parfitt, Roland Park, Cyril Hugh Lynn Parry, Norman Christian Pedersen, Cyril James William Perkins, Kenneth Arthur John Pettet, Kenneth Walter Thomas Pugh, Theodore Grimmer Raynham, John Tudor Reynolds, Leslie William Richardson, John Alexander Ross, John James Roy, Anthony Derek Ruscoe, Gilbert Frank Satchwell, Kenneth John Smedley, Walter Roy Stapleford, Eric George Bond Starling, John Anderson Steed, John Stephens, Ernest Evelyn Stevens, Cyril John Tapsell, Ian Straughan Thomson, Kenneth Frank Venn, Wilfred George John Wallace, Charles Joseph Nicholas Watkin, Thomas Whittaker, Richard Ivor George Whittington, David Howard Williams, Cyril Stanley Wyatt.

Companions.—James William Carr, Arthur George Berkeley Sutherland, Axel Charles Wickman, Jack Noel Williams.

On October 30th, 1939:—

Fellows.—Leonard Frederick George Butler, Leslie Leroy Irvin.

Associate Fellows.—William Donald Arnot, Edward James Brandon, Albert John Brant, Hubert William Jordan Brittlebank, George Barnhill Burnside, Mohamed Aly Cherif, William John Colyer, Frederick William David, Denis Pierpoint Edkins (from Student), Stanley Wason Lane, John Robert Lewin, David Ketchen Marshall, Mansel Thomas, George William Williamson.

Associates.—Patrick Michael Seymour Aldham, Herbert James Allard, Milne Edington, Laurence Richard Morphew (from Student), Albert James Payne, William George Percy Rogers.

Graduates.—Nevil James Ashton (from Student), Granville Clifford, George Noel Fraser Luckie (from Student), Harry Hall Smith (from Student), Peter John Thursby (from Student).

Students.—Henry Verner Becker, Robert Allan Millar Craig, Arthur Frankish, Eric Martin Goodger, Douglas Cole Greenwood, David Matthew McElhinney, Leslie Morgan, Peter George Stannard, William Stuart Sutherland, Eric Herbert Whiteley, Harry Stanley Viney.

Companions.—Ronald Frederick Scott Pearson, Anthony Noel Sergeant.

On November 30th, 1939:—

Associate Fellows.—Leslie Richard Eyre Appleton (from Graduate), George Beaumont (Thesis), Donald Clifford Tyndall Bennett, Jack Halliwell (from Student), Arthur Leslie Haslam (from Associate) (Thesis), Gilbert Frederick William Roper (from Student), Howard Charles Sheath.

Graduates.—John Charles Barr, Keith Beaumont Chamberlain, Stanley Dearing, John Chevalier Hardman (from Student), Leighton Stuart Holt (from Student), William Geoffrey Perrett, Francis Norbert Regan.

Students.—Kenneth Harold Brend, Peter Charles Cleaver, Edmund William Coates, Alexander Stanley Eakins, Walter Frame Gibb, James Philip Lloyd Gwyther, John Hind, Kenneth Henry Jenkins, George Douglas Gergay Ostroumoff, John Garry Owen, Richard James Packman, Grahame Herbert Pearce, George Frederick Pitts, William Samuel Pollinger, Clive Thomas James Ware, Donald Frederick Youldon.

Companions.—Francis Henry Ballinger, John Thomas Bolas, James Falcke, James Hood, Richard Conrad Kernick.

On December 31st, 1939:—

Fellows.—Frederick George Miles, Frank Nixon (from Associate Fellow)

Associate Fellows.—Eric Sydney Allwright (from Student), William Gardner Campbell, Robert Kelman Crowe, Douglas Alexander Fairnie, Robert Hogarth Douglas Forbes (from Student), Vishnu Madhav Ghatage (from Companion), Maurice Green (Thesis), George Henry Holdorf, Frank Holliday (from Associate), Harold Henry Hopkins (from Student), Frank Howarth, Harold Dickenson Jackson, Edward Loveless (from Graduate), Francis Charles Ivor Marchant, Basil Gervase Markham, Elwyn Ivo Banks Marples, Bernard Sidney Massey, Kenneth Holloway Matthews, David Ramsay Milne (from

Student), Harry Frederick Rodgers, Daniel Seed, Robert George Simmons, William Stevenson, Christian Peter Wadsworth, Hugh Carlisle Wescombe, Paul White, Bernard Wilkinson (Thesis).

Associates.—Harry Herbert Aston, Charles Arthur Walter Ball, Albert James Cox, Clifford George Hayward, Frederick William Hughes, William Joseph Latty, Donald Lawler, Alfred James Mankelow, William Arthur Needs, Francis S. Organ, Reginald Frank Payne, Ernest George Pippin, William Pitson, David Edward Pritchett, John Pugh, Jack Reed, Frederick William Stallard, Alexander Thomas Eric Wanek, Bertram Woolcott.

Graduates.—John George Bradley, John Chapman, Gwilym John Cotroceni Davies, Kenneth Roy Davies (from Student), George Guthrie Miller Fitzpatrick, David Anthony Cardnell Harper (from Student), Alfred Henry Higgs, David William Jones, Gwyn John Owen, David Maresco Pearce, Eaton Holroyd Robinson, Charles Douglas Moore Stewart, John Yeadon Tomlinson, Gerard Nunan Verver (from Student).

Students.—John Evelyn Clausen, Andrew William Crichton, Frank Frodin, William Alfred Hibbert, Donald Farley Sargisson, Graham Frederick Simpkin, Donald Stanley Stewart.

Companions.—Terence Noel Hughes, David MacLeish Smith.

BACHELOR OF SCIENCE DEGREE.

The rapid increase in the importance of aeronautical engineering, and the very definite specialisation required, beyond a certain point, led the Council to consider very carefully to what extent aeronautical subjects should be included in engineering examinations for those students who intended, ultimately, to become aeronautical engineers.

It is generally known, following representations of the Society, that National Certificates and Diplomas are endorsed by the President of the Society for Aircraft Engineering, and that for some time questions on aeronautical engineering have been included in the B.Sc. (Eng.) examinations at the University of London.

At the beginning of 1939 the Council were of the opinion that the time had now arrived when aeronautical engineering should be put on the same footing as civil, mechanical and electrical engineering, as far as regards a degree course.

A memorandum stating the reasons for the Council's opinion was addressed to the Academic Registrar at the University of London on the subject of the training of aeronautical engineers and a reply was received that the Board of the Faculty of Engineering would be glad to meet representatives of the Society to discuss the matter fully.

The following were appointed to represent the Society: —

Mr. A. H. R. Fedden, President.
Mr. S. Camm, Member of Council.
Dr. N. A. V. Piercy, Member of Council.
Mr. H. E. Wimperis, Immediate Past-President.
Capt. J. Laurence Pritchard, Secretary.

At the meeting with the Board, Mr. Fedden, the President, and Mr. Wimperis, the Immediate Past-President, briefly explained a number of points in the Society's memorandum, and the urgent need for further facilities for aeronautical engineering training, and answered points raised by the Board of the Faculty of Engineering.

At the end of July, 1939, the following letter was received by the Society, addressed to the Secretary:—

" Dear Sir,

With reference to your letter of December 28th, 1938, I now write to inform you that the Senate at their meeting yesterday resolved that aeronautics be included in the Course for Part II of the Bachelor of Science (Eng.) Examination in the same way as civil, mechanical and electrical engineering are already included in that course.

The question of drawing up regulations is being submitted to the appropriate board of studies.

Yours faithfully,

S. I. WORSLEY,

Academic Registrar."

The regulations referred to in this letter will be published in the Journal in due course. The President and Council, naturally, view with satisfaction the result of their efforts, a result due not only to the important position now reached by aeronautical engineering, but due also to the very sympathetic hearing given to the representatives of the Society by the Board of the Faculty of Engineering at the University of London, under the Chairmanship of Professor G. T. R. Hill.

The President and Council have had every aspect of the training of aeronautical engineering under close review during the past twelve months. In many directions they are pressing for a fuller recognition of the importance of training men (and for providing full facilities for training) now for the future increase in developments which are clearly coming.

ACKNOWLEDGMENTS.

The Council acknowledge with grateful thanks the gift of early numbers of the Journal and books for the Library from the following:—Major A. R. Low, Fellow, Mr. T. Henry Turner, Mr. V. H. Haefner, Mr. H. J. Wolfsohn, Major R. H. Mayo, Fellow, Mr. G. C. D. Russell, Associate Fellow, Miss L. Chitty, Fellow, Miss B. Etty-Leal, Major B. W. Shilson, Fellow, Mr. W. O. Manning, Fellow.

The Council wish specially to acknowledge the generous gift, in twelve volumes, of extra-illustrated volumes of Tissandier's " Histoire des Ballons " from Dr. Poynton. These volumes are unique and contain many rare and interesting illustrations of original texts showing the development of aviation from the earliest mythological times until 1939.

The generous gift of these volumes, the result of many years' work on the part of Dr. Poynton, will be of outstanding value to the Library of the Society. The volumes are a mine of information on the growth of aviation and it is hoped to prepare a fuller description of them shortly for publication in the Journal, together with notes on the Library of the Society generally, a library which contains the greatest collection of aeronautical literature in the world.

Professor G. I. Taylor, back Journals; and 21 volumes of Abridgements of Patent Specifications, Internal Combustion Engines, complete from 1855 to 1920; a copy of " Through the Overcast, The Art of Instrument Flying," by Assen Jordanoff, presented by Mr. J. V. Holman, Associate; a copy of " Flying," of December, 1901, presented to the Library by Mr. F. R. Simms, M.I.Mech.E., Founder Member and Member.

" Dedication of the Wright Brothers' Home and Shop in Greenfield Village, U.S.A., 1938," from Mr. Griffith Brewer, Vice-President. This copy contains a print from the original negative of the first flight by a heavier-than-air craft on December 17th, 1903. They also wish to acknowledge from Mr. F. R. Simms,

Founder Member and Member, a copy of his Patent No. 1,639 of 1909, the first patent for a " joy-stick " taken out in this country; and from Mr. W. O. Manning, Fellow, a copy of " Air Bubbles and Buoys," published by Spencer Bros., Ltd. The Council also acknowledge with grateful thanks the gift of an original copy of the reprint of the paper read by Mr. F. W. Brearey at the second meeting of the Society (Feb. 28, 1866), containing also a subscription form and a notice of the first meeting (Jan. 12th, 1866), from Sir Frank McClean; and to Mr. R. L. Howard-Flanders of Eiffel's " Nouvelles Recherches sur la Resistance de l'Air et l'Aviation, faites au Laboratoire d'Auteuil " (1914), and also of a photographer's armlet from the Rheims Flying Meeting.

Finance.

The Income and Expenditure Accounts and Balance Sheets of Aerial Science, Limited, and Aeronautical Trusts, Limited, for 1939 are published in this issue of the Journal.

The Income and Expenditure Account of Aerial Science, Limited, shows an excess of expenditure over income for the year of £1,113 4s. 0d., as against an excess of income over expenditure for 1938 of £269 8s. 4d. The excess of expenditure over income is due entirely to the added expenditure of moving into the new headquarters at No. 4, Hamilton Place, the preliminary cost of the 1940 Congress and other non-recurring items.

Journal.

The Income and Expenditure Account of Aerial Science, Limited, gives a summary of the expenditure on the Journal and sundry publications, *e.g.*, advance proofs of lectures, reprints of lectures, reprints of papers, etc. The Income and Expenditure of the Journal is as follows (the figures in brackets are the corresponding figures for 1938):—

	£ s. d.	£ s. d.		£ s. d.	£ s. d.
Printing Cost ...	2831 5 9	(2904 4 3)	Sales	2053 16 9	(1355 11 7)
Postages	385 12 1	(343 12 10)	Advertisements ...	2022 6 6	(2271 1 9)
Other Charges ...	465 11 7	(591 18 2)			
Profit	393 13 10	—		—	(213 1 11) (loss)
	£4076 3 3	£3839 15 3		£4076 3 3	£3839 15 3

Although the Advertisement Revenue has decreased, owing to the stoppage of certain advertisements following the outbreak of war, the Sales revenue has shown the remarkable increase of £700, over 50 per cent. increase. For the first time for many years the Journal shows an excess of income over expenditure.

Officers of the Society.

The Council wish to place on record their appreciation of the work which has been carried out by the Officers of the Society.

Major D. H. Kennedy, O.B.E., F.R.Ae.S., in 1939, completed 13 years' continuous service as Honorary Treasurer of the Society. For many years Chairman of the Finance Committee and during the whole period a member of that Committee, Major D. H. Kennedy has given invaluable help in all matters pertaining to the Finances of the Society.

Mr. A. N. D. Smith completes his twelfth year as Honorary Accountant. During those years his advice and practical help have enabled the Society to save considerable sums of money in income tax and other directions.

Mr L. A. Wingfield, the Solicitor to the Society, has during the past year, advised the Council on many important legal matters concerned with the taking over of No. 4, Hamilton Place, and the many trust deeds which have been drawn

up by donors to the Endowment Fund. In particular, Mr. Wingfield was successful in his appeal, on behalf of the Society, against payments of rates at No. 4, Hamilton Place, resulting in the saving of approximately £500 per annum.

The Council particularly wish to thank the Chairmen and Members of Committees of Council and representatives of the Society on other bodies and committees during the year.

The Finance Committee, under the Chairmanship of Mr. W. C. Devereux, have had considerably increased work and responsibility during the year, following the rapid increase in expenditure when No. 4, Hamilton Place was bought and taken over and furnished.

The Grading Committee has done invaluable work during the year, scrutinising with great care every application for membership, with the view constantly in mind, of admitting only those candidates who fully comply with the Rules and have proper qualifications and experience.

The Society owes to all the Committees and Council representatives a deep debt of gratitude for their voluntary work on its behalf. It is due to them that many of the proposals which come before the Council are thoroughly examined before decisions are made.

OBITUARIES.

The Council record with great regret the deaths of the following members during the year :—

Ig. A. G. von Baumhauer, *Fellow.*
Captain F. L. M. Boothby, *Fellow.*
Mr. G. L. O. Davidson, *Founder Member.*
Mr. I. J. Gerard, M.Sc., Assoc.M.Inst.C.E., *Associate Fellow.*
Mr. K. Mitchell, *Student.*
Mr. J. T. Morton, *Associate Fellow.*
Mr. J. L. J. Rowland, *Student.*
Mr. P. N. Willoughby, *Associate Fellow.*

Ig. A. G. VON BAUMHAUER, *Fellow.*

Albert Gillis von Baumhauer was born in Holland in 1881 and was trained at the Technical High School at Delft, at Zurich, and for a time under Professor Prandtl. Until 1937 he was in the Aeronautical Research Department at Amsterdam, where he carried out model and full-scale experiments. He was particularly interested in wing flutter and the breaking away of the air flow from wing surfaces and its effect on stability. Baumhauer was a member of the Committee of Airworthiness for Civil Aircraft, and the inventor of a number of aeronautical instruments. He was also an A licence pilot and a C licence sailplane pilot.

Von Baumhauer was not only an outstanding aeronautical engineer, but a man who had a particular charm which enabled him to get on with all nationalities. He was, indeed, a first class linguist, and able to lecture on the technical side of aviation in a number of languages. On March 2nd, 1939, he lectured before the Society on " Testing the Stability and Control of Aeroplanes." A few days afterwards he sailed for America and was killed on March 18th when the Boeing States liner, in which he was flying, met with disaster.

His death was a severe loss not only to Dutch but to world aviation. He had personal friends in every country who mourned him for his great humane qualities as well as for the loss to the world of such a brilliant engineer.

Captain F. L. M. BOOTHBY, *Fellow.*

Captain F. L. M. Boothby, Fellow of the Society, was born on November 13th, 1881, and entered the Navy where he qualified as a torpedo specialist. In 1910-11 he was chosen to help to supervise the construction of the " Mayfly," Naval

[*Continued on page* 416

THE ROYAL

(Aerial

Balance Sheet,

	£ s. d.	£ s. d.
Share Capital—		
Authorised—		
20 Shares of 1/- each	1 0 0	
999 Shares of £1 each	999 0 0	
	1000 0 0	
Issued—19 Shares of 1/- each, fully paid..		19 0
Sundry Creditors		1045 2 3
Subscriptions and Other Amounts Received in Advance		332 15 6
Amount due to Subsidiary Company—		
Aeronautical Trusts Limited on Current Account		572 15 6
Staff Pensions Fund		309 4 10
Surplus—		
Capital Accumulations Account—		
Balance at 31st December, 1938	9750 16 10	
Less—Amount transferred to Endowment Fund	9750 16 10	
Income and Expenditure Account—		
Balance at 31st December, 1938 ... ... 2872 19 3		
Less—Excess of Expenditure over Income for year to date 1113 4 0	1759 15 3	1759 15 3
		£4020 12 4

We report to the Members that we have examined the above Balance Sheet with the Books are of the opinion that the Balance Sheet is properly drawn up so as to exhibit a true and correct information and the explanations given to us and as shown by the Books of the Society.

3, Frederick's Place, Old Jewry, London, E.C.2.
27th March, 1940.

Income and Expenditure Account

	£ s. d.	£ s. d.	£ s.
			1938 Figu
To Establishment Expenses—			
Ground Rent, Heating, Lighting and Insurance		1285 2 0	(931 15
,, Office and Staff Expenses—			
Salaries	2391 14 7		(1682 15
Printing and Stationery	832 6 7		(381 8
Postages and Telephone	416 16 1		(268 2
Other Charges	1061 16 11	4702 14 2	(671 8
			(3003 14
,, Meetings		128 6 5	(152 10
,, Library Expenses		40 10 3	(61 9
,, Prizes and Donations		32 18 6	(5 5
,, Dinners and Receptions—			
Expenses	909 2 4		
Less—Receipts	19 2 6	889 19 10	(165 2
,, 1940 Congress...		263 15 11	
,, Legal and Professional Charges		273 15 2	(200 8
,, Staff Pensions Fund...		100 0 0	(100 0
			(Surplus f Income ov Expenditu £269 8
		£7717 2 3	

W. C. DEVEREUX, *Chairman, Finance Committee.*
A. N. D. SMITH, *Honorary Accountant.*

AERONAUTICAL SOCIETY

Science Limited)

31st December, 1939.

	£ s. d.	£ s. d.
Printed Books, Bindings, Old Prints, etc., at cost, less amounts written off		50 0 0
Stock of JOURNALS *and other Publications*		1 0 0
Sundry Debtors		425 16 5
Investment in Subsidiary Company—		
Aeronautical Trusts Limited—		
21 Shares of 1/- each, fully paid, at cost		1 1 0
Staff Pensions Fund Investment, at cost—		
£188 3s. 11d. 4½ % Conversion Loan, 1940/44	200 0 0	
Cash at Bank	9 4 10	
Amount due from General Account	100 0 0	309 4 10
Cash at Bank and in Hand		3233 10 1
		£4020 12 4

A. H. R. FEDDEN, *Director.*
D. H. KENNEDY, *Director.*

of the Society, and have obtained all the information and explanations we have required. We view of the state of the Society's affairs as at 31st December, 1939, according to the best of our

(Signed) PRICE, WATERHOUSE & CO.

for the Year ending 31st December, 1939.

	£ s. d.	£ s. d.	£ s. d.	1938 Figures
By Annual Subscriptions		5084 1 0	(4520 19 6)	
,, Interest on Investments (*Less* Tax)	184 5 9		(214 6 2)	
,, Interest on Deposit Account	23 1 4		(3 10 7)	
,, Income Tax Recovered	106 7 1	313 14 2	(32 13 2)	
			(250 9 11)	
,, Donations		500 0 0	(500 0 0)	
,, Examinations—				
Fees Received	192 16 6		(189 9 6)	
Less Expenses	174 1 0	18 15 6	(189 5 0)	
			(4 6)	
,, Receipts from JOURNAL and Sundry Publications—				
Sales	2053 16 9		(1355 11 7)	
Advertisement Revenue	2022 6 6		(2271 1 9)	
	4076 3 3		(3626 13 4)	
Less Expenditure—				
Printing Costs 2831 5 9			(2904 4 3)	
Postages 385 12 1			(343 12 10)	
Other Charges 465 11 7	3682 9 5	393 13 10	(591 18 2)	
			(Loss £213 1 11)	
,, Garden Party—				
Receipts	1912 18 8		(923 0 0)	
Less Expenses	1619 4 11	293 13 9	(879 12 3)	
			(43 7 9)	
,, Balance, being Excess of Expenditure over Income for year to date, carried to Balance Sheet		1113 4 0		
		£7717 2 3		

AERONAUTICAL

Balance Sheet,

	£ s. d.	£ s. d.	£ s. d.
Share Capital—			
Authorised—40 Shares of 1/- each		2 0 0	
Issued—21 Shares of 1/- each fully paid			1 1 0
Pilcher Memorial Fund—			
Capital Account—As at 31st December, 1938		99 14 0	
Income Account—Balance at 31st December, 1938 ...	32 6 4		
Less Excess of Expenditure over Income for year to date	19 4	31 7 0	131 1 0
Usborne Memorial Fund—			
Capital Account—As at 31st December, 1938		109 2 5	
Income Account—Balance at 31st December, 1938 ...	49 8 0		
Less Excess of Expenditure over Income for year to date	1 1 0	48 7 0	157 9 5
Herbert Akroyd Stuart Fund—			
Capital Account—As at 31st December, 1938		688 19 0	
Income Account—Balance at 31st December, 1938 ...	226 10 7		
Add Income for year to date	23 18 0	250 8 7	939 7 7
R.38 Memorial Fund—			
Capital Account—As at 31st December, 1938		978 3 10	
Income Account—Balance at 31st December, 1938 ...	405 19 6		
Add Income for year to date	36 13 10	442 13 4	1420 17 2
Edward Busk Memorial Fund—			
Capital Account—As at 31st December, 1938		449 6 1	
Income Account—Balance at 31st December, 1938 ...	84 9 10		
Less Excess of Expenditure over Income for year to date	1 6 0	83 3 10	532 9 11
Wilbur Wright Memorial Fund—			
Capital Account—Balance at 31st December, 1938 ...		1398 9 9	
Income Account Balance at 31st December, 1938 ...	134 12 11		
Add Surplus of Income over Expenditure for year to date	5 12 8	140 5 7	1538 15 4
Simms Gold Medal Fund—			
Capital Account—As at 31st December, 1938		250 0 0	
Less—*Income Account*—			
Deficiency at 31st December, 1938	43 19 6		
Less Income for year to date	12 19 0	31 0 6	218 19 6
Royal Aeronautical Society Endowment Fund—			
Capital Account—Balance at 31st December, 1938 ...		12211 12 11	
Add Donations received in 1937 and 1938 transferred from Aerial Science Limited		9750 16 10	
Donations received during year		28928 9 4	
Entrance Fees received during year		411 12 0	
		51302 11 1	
Less—*Income Account*—			
Excess of Expenditure over Income for year to date		253 16 7	51048 14 6
			£55988 15 5

We report to the Members of Aeronautical Trusts Limited, that we have examined the above explanations we have required. We are of opinion that the Balance Sheet is properly drawn up December, 1939, according to the best of our information and the explanations given to us and as

3, Frederick's Place, Old Jewry, London, E.C.2.
27th March, 1940.

TRUSTS LIMITED

31st December, 1939.

	£ s. d.	£ s. d.
Pilcher Memorial Fund—		
£115 6s. 10d. 3½ % War Loan at cost	116 5 0	
Cash at Bank	14 16 0	131 1 0
Usborne Memorial Fund—		
£113 3½ % War Loan at cost	114 11 1	
Cash at Bank	42 18 4	157 9 5
Herbert Akroyd Stuart Fund—		
£683 1s. 0d. 3½ % War Loan at cost	698 19 0	
Cash at Bank	240 8 7	939 7 7
R.38 Memorial Fund—		
£1048 11s. 2d. 3½ % War Loan at cost	1098 18 10	
Cash at Bank	321 18 4	1420 17 2
Edward Busk Memorial Fund—		
£284 4s. 2d. 3½ % War Loan at cost	284 4 2	
£217 London Transport 4½ % "A" Stock, at cost	199 4 6	
	483 8 8	
Cash at Bank	43 18 11	
Amount due from Aerial Science Limited	2 8 8	
Amount due for refund of Income Tax	2 13 8	532 9 11
Wilbur Wright Memorial Fund—		
£1246 18s. 1d. 3½ % Conversion Stock, at cost	1000 0 0	
£550 Canada 4 % Stock, 1940/60, at cost	531 10 9	
	1531 10 9	
Cash at Bank	8 2 1	
Amount due for refund of Income Tax	6 1 0	
	1545 13 10	
Less—Amount owing to Aerial Science Limited	6 18 6	1538 15 4
Simms Gold Medal Fund—		
£287 16s. 1d. India 4½ % Stock, 1958/68, at cost	250 0 0	
Cash at Bank	38 17 0	
	288 17 0	
Less—Amount owing to Aerial Science Limited	69 17 6	218 19 6
Royal Aeronautical Society Endowment Fund—		
Leasehold Property at Cost—Less amount written off—		
4, 8, and 9, Hamilton Place	11640 0 0	
Furniture at cost, *less* depreciation	4168 2 6	
Investments at Cost— £ s. d.		
£15103 15s. 3d. 3½ % War Loan 14000 0 0		
£6474 11s. 7d. 3½ % Conversion Stock 6192 5 1		
£1000 3 % Defence Bonds 1000 0 0		
£629 16s. 4d. London County Council 2¾ % Stock, 1960/70 ... ... 600 0 0		
£2367 12s. 7d. Manchester 3 % Redeemable Stock, 1952/55 ... ... 2388 12 11		
£4100 London & North-Eastern Railway 3 % Debenture Stock 3162 6 3		
£3100 London, Midland & Scottish Railway 4 % Debenture Stock 3162 19 9	30506 4 0	
Cash at Bank	210 16 4	
Amount due from Aerial Science Limited	647 2 10	
Amounts due for refund of Income Tax, etc. ...	3880 12 10	
	51052 18 6	
Less—Amount owing for Legal Charges	4 4 0	51048 14 6
Cash in Hand		1 1 0
		£55988 15 5

Balance Sheet with the books of the Company and have obtained all the information and so as to exhibit a true and correct view of the state of the Company's affairs as at 31st shown by the books of the Company.

(Signed) PRICE, WATERHOUSE & CO.

AERONAUTICAL

INCOME & EXPENDITURE ACCOUNTS

Pilcher

	£ s. d.
To 1939 Award	5 0 0
	£5 0 0

Usborne

To 1939 Award	5 0 0
	£5 0 0

Herbert Akroyd

To Income for year carried to Balance Sheet	23 18 0
	£23 18 0

R.38

To Income for year carried to Balance Sheet	36 13 10
	£36 13 10

Edward Busk

To 1939 Awards	21 0 0
	£21 0 0

Wilbur Wright

To 1939 Award	60 0 0
,, Surplus of Income over Expenditure for year carried to Balance Sheet	5 12 8
	£65 12 8

Simms Gold

To Income for year carried to Balance Sheet	12 19 0
	£12 19 0

Royal Aeronautical Society

To Legal Charges	132 18 0
,, Amortisation of Leasehold Property	480 16 6
,, Depreciation of Furniture	106 18 3
	£720 12 9

TRUSTS LIMITED

FOR THE YEAR ENDED 31st DECEMBER, *1939.*

Memorial Fund.

	£ s. d.
By Interest on Investments (gross)	4 0 8
,, Balance of Expenditure over Income for year carried to Balance Sheet	19 4
	£5 0 0

Memorial Fund.

By Interest on Investments (gross)	3 19 0
,, Balance of Expenditure over Income for year carried to Balance Sheet	1 1 0
	£5 0 0

Stuart Fund.

By Interest on Investments (gross)	23 18 0
	£23 18 0

Memorial Fund.

By Interest on Investments (gross)	36 13 10
	£36 13 10

Memorial Fund.

By Interest on Investments (*less* Tax)...	17 0 4
,, Refund of Income Tax	2 13 8
,, Balance of Expenditure over Income for year carried to Balance Sheet	1 6 0
	£21 0 0

Memorial Fund.

By Interest on Investments (*less* Tax)	59 11 8
,, Refund of Income Tax	6 1 0
	£65 12 8

Medal Fund.

By Interest on Investments (gross)	12 19 0
	£12 19 0

Endowment Fund.

By Interest on Investments (less Tax)	332 17 4
,, Interest on Deposit Account	17 18 10
,, Refund of Income Tax	116 0 0
,, Balance of Expenditure over Income for year carried to Balance Sheet	253 16 7
	£720 12 9

Continued from page 409]

Airship No. 1, which was wrecked on leaving its shed. Boothby continued to take a deep and lifelong interest in airships, and largely on his advice the Parseval airship was bought from Germany, and did useful work on the outbreak of war on patrol.

In 1915 Boothby was given the command of the Barrow airship station and in the following year he was transferred to Howden, and afterwards to the experimental station at Pulham, in Norfolk. In 1919 Boothby retired from the R.A.F. and returned to the Navy. He never, however, lost his interest in the air. He invented an excellent crash-proof petrol tank, which had many merits but suffered from that fatal vice, where anything pertaining to aircraft is concerned, of being heavy.

Boothby was a man who was fertile of ideas, an enthusiast in all he undertook, and a man of great charm. In another country many of his suggestions would have received more attention and some appeared to have held out possibilities of great success. He died on January 3rd, 1939, at the comparatively early age of 58.

INGLIS JOSEPH GERARD, *Associate Fellow.*

Inglis Joseph Gerard was born on September 18th, 1889, and was educated at Leeds Modern School and Leeds University, where he took an Honours B.Sc. degree in Mechanical Engineering in 1911. He was a pupil of Messrs. John Fowler and Co., at Leeds, and afterwards chief designer to Messrs. B. W. Clegg and Son. In 1914 he joined the staff of the Royal Aircraft Establishment, and was responsible for the calculation of stresses in aircraft structures and the development of improved methods of testing aircraft structures. Gerard was responsible for the design of a large number of new types of testing machines and distortion measuring apparatus to suit the special requirements of aircraft construction. His lecture on "Tests of Aircraft Components," in February, 1932, before the Society was an outstanding example of his work and experience. He lectured on a number of occasions before the branches of the Society on testing methods.

Gerard was a man who made many friends and no enemies. He brought an enthusiasm to bear on his subject which was uncommon and refreshing, and his judgment on the subject of testing was extremely sound. His sudden and unexpected death has proved a severe loss where his advice and experience were most valued.

PERCIVAL NESBIT WILLOUGHBY, *Associate Fellow.*

The death of Percival Nesbit Willoughby, at the early age of 36, in one of his own aircraft, was the loss of a very original thinker and designer. Managing director of the company which bore his name, he carried out many experiments and research work on the Delta aerofoil, and a new form of aircraft, which opened out great possibilities. He was for some years an Associate of the Society and in 1937 became an Associate Fellow. The Willoughby Delta machine, *St. Francis*, which crashed at Caulcott, near Brighton, in July, 1939, was demonstrated at the Royal Aeronautical Society's Garden Party in May, 1939.

REVIEWS.

THE AIR NAVIGATOR'S SELF-EXAMINING HANDBOOK.

By E. Brook Williams and W. J. V. Branch. Brown, Son and Ferguson. 10/6.

This book, as the authors point out in the preface, is not complete in itself, but is intended to be read in conjunction with " Nicholls' Concise Guide " and the other textbooks mentioned. It is important that the would-be purchaser should realise this, for the difficulty that most students experience when preparing the Second Class Navigator's examination (and still more so in the case of the First Class) is, that it is impossible to obtain sufficiently detailed explanations from textbooks to enable them to arrive at a true appreciation of the theory underlying certain mathematical or meteorological processes.

In the book under review, a large number of presumably accurate answers have been worked out for a varied selection of questions. On the other hand, meteorological papers have not been treated at all, except to refer the pupil to certain publications.

As it stands, the book at its price of half-a-guinea would be an expensive purchase for students preparing the examination. On the other hand, it would be invaluable to navigation instructors in saving them the time and work of producing questions and answers for their pupils.

SOARING WINGS: A BIOGRAPHY OF AMELIA EARHART.

By George Palmer Putnam. G. G. Harrap and Co., Ltd. 11/-.

" Ah, did you once see Shelley plain?
And did he stop and speak to you?". . .

Once or twice in a generation is born one of those outstanding personalities—a Shelley, a d'Annunzio, a Rupert Brooke—who capture the public imagination not so much for what they do as for what they are. They have something of the child, something of the bird, and a supreme indifference to convention. Mr. Putnam's book confirms the impression that Amelia Earhart was one of these rare spirits; that, even had she never sat at the controls of a plane, the world would still have gained by her existence.

From its pages she emerges just as the many beautiful photographs show her: gallant, vivid and trenchant, with a mind that produced epigrams as inevitably as less gifted minds utter platitudes: " A pilot whose landplane falls into the Atlantic is not consoled by caviare sandwiches." " As a sex, women seem to regard matrimony as a highly honourable retreat from business failure." " The trenches . . . are the last remaining strongholds of men. I suspect that men might rather vacate the arena altogether than share it with women." Equally caustic is her pencilled comment upon a " written-up " article submitted by an editor for her signature: " Apple sauce! . . . Much as I'd like the cheque, wash this out. Such drivel!"

Amelia Earhart, as her husband reminds us, is the only woman who has ever been invited to a Council Dinner of the Royal Aeronautical Society, and after reading this book we feel that she was entitled to this honour, not only as a flyer but also as a personality.

Keeping himself consistently in the background, Mr. Putnam nevertheless emerges as a sympathetic figure, who played with tact and dignity his difficult *rôle* of " Amelia Earhart's husband." And he has the rare insight not to write about the " tragedy " of her end. " Beauty and adventure have a certain value

of their own, which can be weighed only in spiritual scales," said "A.E."; and again: "Who could refuse such a shining adventure?" That the shining adventure led her over the borders of death was a tragedy for the world; for her, the real tragedy would have been to have lived and grown old.

BRITAIN'S AIR POWER.

E. Colston Shepherd. Oxford Pamphlets of World Affairs, No. 28. Clarendon Press, 1940. Price 3d.

Mr. Shepherd, one time aeronautical correspondent for the *Times* and now editor of the *Aeroplane*, is an authority who can look at the hive as a whole without getting bees in his bonnet. This short summary of the broad principles of air strategy and the main types of aircraft required to carry it out is clear, concise and convincing. Mr. Shepherd throws a vivid light on what is really involved by such a short phrase as coastal patrol, the constant watch, the accurate navigation, and the unending strain to all concerned. The work of the Coastal Command and Fleet Air Arm, the Bomber and the Fighter, and the Reconnaissance machines is explained simply and without that technical overgrowth which makes it difficult, if not impossible, for those who have not made a study of air tactics to understand. There is a fine description of the fight of a bomber over Germany, "engaged on its work in some of the worst weather Northern Europe is capable of producing." This pamphlet is a very excellent, well written and informative threepenny worth.

WIND, SAND AND STARS.

Antoine de Saint Exupéry.

We regret that, in our review of this book last month, the publisher's name was omitted. The book is published by Messrs. Wm. Heinemann, price 10/6.

FORECASTING WEATHER.

Sir Napier Shaw. Constable and Co. 1940. £2 2s. 0d. net.

This is the third edition of Sir Napier Shaw's work originally published in 1911, and revised and enlarged in a second edition in 1923. The present edition is identical with the second edition, save for some sixty pages at the end, "Sixteen Years Progress in Forecasting Weather," by R. G. K. Lempfert, C.B.E., late Assistant Director of the Meteorological Office, and for some years personal assistant to Sir Napier Shaw when the latter was Director of the Meteorological Office.

These new pages, few though they may be unfortunately, are nevertheless of great importance. As Mr. Lempfert rightly remarks in his opening paragraph, "Rapid development has taken place in the theory and more particularly the practice of forecasting during the sixteen years which have elapsed since the second edition of this work was issued. If one may include under the heading practice the arrangements for the collection of data and the distribution of weather reports, the changes may fairly be described as phenomenal." It is undoubtedly due to the stimulus of the demands of aviation which has led to this result. One little thing will show how much the weather forecasts had become part of public news. The outbreak of war saw the end of the B.B.C. announcements of weather reports and nothing has been missed so much. The British public, indeed, had become weather conscious, something they certainly were not when Sir Napier Shaw first wrote this book.

This last section is one of profound interest. Most people knew there was an international net gathering in the weather news for experts to digest and present in easily assimilated form to the ever-increasing number of customers. Here is the complete story, however, and a remarkable one it is. Over a thousand ships of the world's merchant navies broadcasting the weather through which

they were passing, four times a day; over sixty wireless stations receiving the ships' messages and passing them on to 19 different national meteorological services; special codes and arrangements to prevent the air being jammed by meteorological wireless; are only parts of the great jig-saw which has to be fitted together at high speed by experts before the final result is published.

New conceptions have come into being since 1923. "Air Masses and Fronts," the title of Chapter XXIX, outlines a conception which is now widely used in forecasting. Information obtained from more and more observatories of the upper air, by aircraft, is proving valuable to the meteorologist. One of the very newest and most difficult problems is forecasting the conditions under which ice formation on aircraft takes place.

"Forecasting Weather" has stood the test of time and requires no further praise than that. The only pity of it is that it costs £2 2s. 0d. a time, for though a work for experts, it is also one which many of those interested in flying would like to have on their shelves. The weather has ceased to be the privilege of the few, and a depression over Ireland is something which appeals (or does not appeal) to the many.

THE AIR IS THE FUTURE CAREER.

"H.W." Hutchinson and Co. 1939. 6/- net.

Many will remember reading those fine books by "H.W.," "Something New Out of Africa" and "Air Over Eden." Those who did will eagerly welcome this new book all about the Air Force, and written primarily for boys. "H.W." has made a primary mistake in thinking this book is one for the rising generation only. It is for everyone, of any age, who has any use for fine writing, has any imagination of the greatness that lies ahead in the air, and has appreciation for tales of heartening deeds.

"H.W." begins with an outline of the Royal Flying Corps. What greater, more poignant summing up of their work can be given than this:—

"The Army and the Navy can claim as great a sense of duty, and no doubt as grave a risk, but they died among each other. The R.F.C. went out over the snow of war, like Oates on his way back from the South Pole, that their friends below might have a better chance of dear life."

This preliminary brilliant chapter on the old R.F.C. is all too brief. It is followed by a chapter on the Royal Naval Air Service. It is not given to every man to fall out of an aeroplane 300 feet up and get away with it, as the author did. He fell in the Suez Canal, and as he naively remarks, "Incidentally it also gave me the high-diving record of the world, although I did not know much about it at the time!"

The Independent Air Force receives its merited tribute. In this chapter the author recites the most remarkable send-off any second lieutenant could have, by the whole audience of Daly's Theatre! Who, when reading the following pages on the V.C.'s of the R.F.C., R.N.A.S. and R.A.F., will not be stirred by the glorious traditions so swiftly built up in those short years of glory?

"The lonely heroism displayed by airmen remained all too often unseen and unsung. So many did not return from their adventures. One among others, known to me personally, rammed his opponent. He had been given a few months to live from an incurable disease, and chose this silent service to his country's cause. At the time only a privileged few, first sworn to secrecy, knew the truth; quiet words, spoken with a catch in his throat the evening before he went forth on his last patrol."

The names and deeds of Albert Ball, Rhodes-Moorhouse, Warneford, Insull, Leafe Robinson, Bishop, McCudden, Mannock, and others are here recorded in words and phrases which start the heart leaping, as do the squadron records which follow. Here is tradition in the making, stories which will be told for all time wherever air people meet. I wish I could quote the whole of the remark-

able chapter of the adventures of Captain W. C. A. Meade and Captain Smith on their air reconnaissance from the St. Male Atoll to Ari Atoll, ending in being stranded on Felitau Island with only cocoanuts and twelve chickens. Boiled chicken and cocoanuts were the only item on the menu.

" The Air is the Future Career " is just such a book to put in the hands of all those, and many still remain, despite the critics, who are masters of their fate and captains of their souls. For this is a book of high adventure, ably told, a delight to read.

How the Air Force Defends Us.

Major C. C. Turner, A.F.R.Ae.S. Allen and Unwin, Ltd. 1940. 5/- net.

Major Turner is one of the old pioneers. He has, for over 30 years, been closely associated with flying and holds one of the earliest pilot's certificates, as well as a balloon pilot's certificate. He writes, indeed, with a knowledge and experience given to few.

This new book of his is concerned almost wholly with defence against air attack on Great Britain. He begins with a chapter on " How the Air Force Got Ready," and significantly in his first paragraph, recalls the massed R.A.F. flights over France. " These flights were of great importance as training, and they should have been a warning to Germany."

Major Turner explains in considerable detail the various methods of air defence, the balloon barrage and how it functions, reasons for the black-out, the observer corps, searchlights, and anti-aircraft guns.

" I am confident," he writes, " that the defence system which has been organised is highly efficient, and is calculated to effect a fairly early discouragement of an enemy."

Major Turner very rightly criticises the exaggerations which have been so persistently put forward of the size and quality of the German Air Force. " I do not wish to suggest that Germany was not at the outbreak of war formidable in the air. It is possibly true that she was, on a merely numerical basis, the greatest air power; but some of those who believed any fantastic story, attributing fabulous numbers, unapproachable speeds, tremendous range, and terrifying bomb load capacity per aircraft, may now be wondering how it all came about."

This book gives answers to many questions which are being asked, and can be thoroughly recommended to all who are interested in the methods of air defence, and the whys and wherefores of the defences.

Electricity in Aircraft.

W. E. Crook, A.M.I.E.E., A.F.R.Ae.S. Sir Isaac Pitman and Sons, London. 1940. 5/- net.

This book has been written as a guide to those studying for the Air Ministry Ground Engineer's " X " licence in respect of electrical equipment and magnetos. The seven chapter headings are: Aircraft batteries; aircraft generators; engine starting; aircraft wiring and lighting; miscellaneous electrical equipment; magnetos; and impulse starters, automatic timing devices and sparking plugs.

The author is to be congratulated on the simplicity and conciseness of his text. The descriptions are clear and very much to the point, so that he has been able to put into a very small space, comparatively, a large amount of information for the ground engineer. The book is well illustrated and can be thoroughly recommended.

THE ROYAL AERONAUTICAL SOCIETY
WITH WHICH IS INCORPORATED THE INSTITUTION OF AERONAUTICAL ENGINEERS.

MONTHLY NOTICES,

MAY, 1940.

Reserved Occupations.

The following is an extract from a letter received by the Society from the Ministry of Labour:—

"I am directed by the Minister of Labour and National Service to inform you that it has been decided to make the following new entry in the Schedule of Reserved Occupations:—

Student engineering apprentice or learner—reserved at and above the age of 18 years.

This entry relates only to a man employed in industry or under articles to a professional engineer who produces a certificate from a university or technical institution or from a professional Institution of Engineers to show that he is within two years of the satisfactory completion of a course of study with a view to offering himself for the first time for:—

(i) An engineering degree;
(ii) An Engineering Higher National Certificate;
(iii) An Associate Membership of the Institutions of Civil, Mechanical or Electrical Engineers, or the Associate Fellowship of the Royal Aeronautical Society;
(iv) Or an examination of similar standing to that of an engineering degree.

The definition is intended to cover under paragraph (iv) the case of other professional institutions of engineers not mentioned specifically under paragraph (iii)."

Council Meeting.

A Meeting of the Council was held in the Offices of the Society on April 24th, 1940.

Present: Mr. A. H. R. Fedden (President) in the chair; Professor L. Bairstow, Mr. R. Blackburn, Mr. S. Camm, Dr. H. Roxbee Cox, Mr. W. C. Devereux, Mr. E. C. Gordon England, Professor F. T. Hill, Major D. H. Kennedy, Captain A. G. Lamplugh, Lieut.-Col. J. T. C. Moore-Brabazon, Mr. F. T. Thomas, Dr. H. C. Watts, Mr. L. A. Wingfield (Solicitor), Mr. R. T. Youngman.

Among the business discussed was the following:—Technical Development of Civil Aviation; Preparation of Abstracts and Summaries; Censorship of the Society's Lectures; Election of Members; Training of Apprentices; Syllabus of the Associate Fellowship Examination.

Election of Members.

Honorary Fellow.—Mr. F. S. Spriggs.

Associate Fellows.—F. Austin (from Associate), A. J. Cope, E. A. W. Dymond, A. W. Seeley (from Associate), W. N. Shuttleworth.

Associate Fellowship Examinations.

The next Associate Fellowship Examinations will be held on Wednesday, May 22nd, and Thursday, May 23rd, 1940. Full particulars will be sent direct to candidates who have entered for the examination.

Annual Subscriptions.

Under the Rules, members who have not paid their subscriptions for the current year by April 1st are not entitled to have the JOURNAL sent to them. It is not always possible to send back numbers of the JOURNAL to those who pay

their subscriptions some time after April 1st, as many of the JOURNALS go out of print. The restrictions on paper make it necessary to print the minimum number of copies required, and it will not be possible to guarantee supplying back numbers of the JOURNAL in future.

The Council wish to thank all those members who have been prompt in paying their subscriptions. By the members supporting the Society particularly at the present time it is possible to legislate ahead and make arrangements which effect considerable saving against having to work from month to month.

Civil Aviation Reports.

The Library has no copies of the first four half-yearly reports on Civil Aviation and the Council would greatly appreciate the gift of any of these reports to complete the set. The reports are: Synopsis of Progress of Work in the Department of Civil Aviation, 1st May, 1919-31st April, 1920 (Cmd. 418); for 1st October, 1919-31st March, 1920 (Cmd. 800); for April 1st, 1920, to September 30th, 1920 (Cmd. 1073).

Wilbur Wright Memorial Lecture.

The 28th Wilbur Wright Memorial Lecture will be given by Dr. H. Roxbee Cox, F.R.Ae.S., on "Looking Forward: Prolegomena for a Detailed Study of the Future of British Civil Aviation," on Thursday, May 30th, 1940, at 6.30 p.m., at the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, W.C.2. The lecture will be followed by the Annual Council Dinner, which will be held at No. 4, Hamilton Place, W.1.

Acknowledgments.

The Council acknowledge with grateful thanks the gift of bound volumes of the Society's Journal from Mr. M. W. S. Templeman, Associate Fellow.

The Council also wish to acknowledge with grateful thanks a donation of £1 1s. to the Endowment Fund from Mr. J. W. C. Logan, Associate Fellow, for the eighth year in succession.

The College of Aeronautical Engineering.

The holder of the Mollison Trophy for 1940, held each year by the student who has shown the highest standard of general efficiency, is R. B. Wilkinson.

The holder for 1940 of the Olley Trophy, held each year by the student showing the best results in the practical and commercial side of aeronautical engineering, is K. R. Davies.

Both these students sat for and passed the Associate Fellowship Examination.

Additions to the Library.

Ref.

UC. 1/5.—National Research Council of Canada:—
Vingt-Deuxième Rapport Annuel du Conseil National de Recherches du Canada, 1938-39.

UF. 3.—Ministère de l'Air: Publications Scientifiques et Techniques:—
No. 157. Introduction à l'Étude des Groupes Motopropulseurs mettant en Jeu les Vitesses Supersoniques. By D. Riabouchinsky. Frs. 35.
No. 158. Contribution à l'Étude des Potentiels de Dissolution. By Mlle. N. Goldowski. Frs. 30.
No. 159. Mesure de la Turbulence à l'Aide d'une Source de Radium. By Mlle J. Roquet. Frs. 12.

UF. 4.—Ministère de l'Air: Bulletins Scientifiques et Techniques:—
No. 89. Recherches sur l'Injection directe dans les Moteurs à Combustion. By J. E. Tuscher. Frs. 25.

UH. 3.—Atti di Guidonia:—
No. 20. Esperienze sistematiche sul Modello di Idrovolante Biscafo "G.I.S. 6," in varie condizioni di assetto e di dislocamento in

relazione alla distanza fre le mezzerie degli Scafi. By Prof. C. Cremona.

No. 21. Considerazioni sulla Progettazione di Eliche per Apparecchi Veloci. By Dr. A. Ferri.

UL. 3.—Institute of Physical and Chemical Research, Tokyo:—
Scientific Papers Nos. 949-954. Various Authors.

UL. 4.—Tokyo Bunrika Daigaku:—
Science Reports Nos. 71-73. October, 1939. Various Authors.

UL. 5.—National Research Council, Tokyo:—
Japanese Journal of Engineering. Abstracts, 1938.

V.6/41.—Institution of Mechanical Engineers:—
Proceedings, Vol. 142 (July-Dec., 1939).

Y. 19.—Air Ministry:—
D.T.D. Specifications: Nos. 69A, 163A, 175A, 216, 218, 265A, 279, 281, 283A, 301, 307, 318A, 324, 326, 329, 330, 331, 335, 336, 337, 339A, 342, 343, 344, 346, 348, 350, 351, 354, 355, 356, 357, 361, 363, 364, 367, 369, 374, 375, 376, 377, 379, 382, 383, 390, 910A, 912.

Y. 24.—International Tin Research and Development Council: Publications:—
No. 96. The Determination of Tellurium in Tin-Rich Alloys. By W. T. Pell-Walpole.

B.a.141(G)—Bau-Beschreibung: Ju 52/3m. Junkers Flugzeugwerk, 1936.

B.a.142(G).—Bau-Beschreibung: Ju. 86. Junkers Flugzeugwerk, 1936.

B.a.143/Y.3.ii.J.—Technical Development of Ju. 160. (Reprint from "Engineering Progress") By H. Pohlmann. 1935.

B.a.144(G)/Y.3.ii.J.—Eine Familie dreimotoriger Junkers-Flugzeuge. Ju. 52/3m. By E. Billeb. 1935.

B.a.145/Y.3.ii.J.—The Junkers Double Wing. (Reprint from the "Aeroplane," 6.3.35.)

B.a.146/Y.3.ii.J.—Dessau's Giant. (Ju. 90.) (Reprint from "The Aeroplane," 29.9.37.)

B.g.72/Y.3.ii.D.—Plane Facts. Deutsche Lufthansa. (Published by Gebr. Radetski, Berlin.)

BB.c.53(G)/Y.1.b.7a.—Vom Windmühlenflügel zur Verstell-Luftschraube. By Dr. Fritz Flucke. (Reprint from "Luftwelt," May/June, 1938.)

D.a.B.65/Y.20.ii.—Parliamentary Debates: House of Commons Official Report. Vol. 349, No. 137. July 10th, 1939. H.M.S.O. 6d.

D.a.B.66/Y.20.ii.—Parliamentary Debates: House of Commons Official Report. Vol. 348, No. 117. June 12th, 1939. H.M.S.O. 6d.

D.a.B.67/Y.20.ii.—Parliamentary Debates: House of Commons Official Report. Vol. 357, No. 30. February 28th, 1940. H.M.S.O. 6d.

D.c.67.—Air Planning in the County of Essex. By Norman and Dawbarn. (Printed by Whitehead Morris, Ltd.) 1936.

D.c.68 and 69/Y.4.i.14 and 15.—Rand Airport Yearbook, 1938 and 1939. Sholto Douglas, Johannesburg.

D.e.23/Y.6.a.9a.—Economy of Junkers Civil Aircraft. (Reprint from "Junkers Nachrichten," Sept., 1937.)

D.f.18/Y.12.a.4a.—Sicherheit durch Junkers-Bauweise. Junkers Flugzeugwerk, Dessau. 1937.

D.f.19/Y.12.a.9.—Difficult Night Mail Flight of a Junkers Ju 53/mW from Rio de Janeiro to Bahia. Junkers Flugzeugwerk, Dessau. (undated)

EE.c.50/Y.7.d.J.—Development of the Junkers High-Power Aero Engine Jumo 210. (Reprint from Junkers Nachrichten, Feb. 1938.)

EE.c.51/Y.7.d.J.—Junkers Benzin Flugmotor Jumo 210. (Stencil.)

EE.c.58.—Aircraft Engines, Vol. 1. By A. W. Judge. Chapman and Hall. 1940. 16/-.

EE.f.32/Y.7.b.3a.—Junkers Diesel Engines. (Interleaved German and English text.) By Dr. J. Gasterstädt. Junkers-Flugzeugwerk. 1936.

G.a.34.—The Heavy Industry of Manchoukuo. (East Asia Economic Intelligence Series, No. 3.) Japan Economic Federation, 1940. Price, 80 Sen.

G.c.11.—Metallurgical and Industrial Radiology. By Kenneth S. Low. Sir Isaac Pitman and Sons, 1940. 7/6.

G.d.6./Y.13.a.5a.—Modern Methods of Sheet Metal Working in Metal Aircraft Construction. Junkers Flugzeugwerke, 1937.

G.e.A.52/Y.13.c.D.—Der Flugzeugbaustoff (Duralumin). Reprint from "Junkers-Nachrichten," 1937.)

G.e.D.9 and 10/Y.13.c.P.—Cellulose Acetate in Aircraft Manufacture. By M. Lewin. (Reprint from "Plastics," Feb., 1940.) Two copies.

J.b.14.—A Statistical Analysis of the Monthly Rainfalls in the Amraoti District (Berar). By N. Rajagopalan. (Vol. VIII No. 84 of India Meteorological Department Scientific Notes.) 1939. 6d.

Y.30.ii.—Smithsonian Institution, Washington: Reprints.

J.g.140.—No. 3494. The Sun and the Atmosphere. By Harlan T. Stetson. 1939.

J.g.141.—No. 3503. Ice Ages. Sir George Simpson. 1939.

J.g.142.—No. 3506. The Meteorology of Great Floods in the Eastern United States. By C. F. Brooks and A. H. Thiessen. 1939.

K.b.6.—No. 3522. The Natural Limits to Human Flight. By H. E. Wimperis. 1939.

M.c.49/Y.18.a.29.—Lorenz Flugzeug-Blindlandungs-Anlagen: Sender. (Interleaved: English, German, Spanish.) C. Lorenz, Berlin (Pub. No. 583). 1937.

M.c.50/Y.18.a.30.—Lorenz Blind Landing Receiver. (Pub. 602.) 1937.

M.c.51/Y.18.a.31.—Lorenz Blind Landing Beacon. (Pub. 598.) 1937.

M.d.16.—Electricity in Aircraft. By W. E. Crook. Sir Isaac Pitman and Sons, 1940. 5/-.

N.a.58.—Abstracts of Dissertations approved for the Ph.D., M.Sc. and M.Litt. Degrees in the University of Cambridge (1938-39). Cambridge University Press, 1940.

N.a.59/PN.1.a.8.—Quantitative Spectrographic Analysis with the Microphotometer. Part I. A Review of Published Work. By D. M. Smith. British Non-Ferrous Metals Association. 1939. 2/-.

N.a.60.—Light and Colour in the Open Air. By M. Minnaert. G. Bell and Sons, 1940. 15/-.

Q.a.84.—British Standards Institution Handbook. January, 1940. 1/6.

Q.a.57.—Industrial Arts Index. 1939. (Vol. 27.) H. W. Wilson, New York. 1940.

RR.102.—Truing-up of Aeroplanes. The Air Department, 1916.

T.a.60/Y.26.—Umberto Nobile, Notizie e Pubblicazioni Scientifiche. U. Nobile. Tipografia Cuggiani, Rome, 1937.

TT.a.28.—T.1000: Roman eines Riesenflugzeuges. By Hans Richter. Adolf Sponholz Verlag, Hannover. 1927. RM. 5.50.

TT.a.30.—Wings. By J. M. Saunders. (German Translation.) Schreitersche Verlags-Buchhandlung.

Forthcoming Arrangements.

May 22nd and 23rd.—Associate Fellowship Examinations.

May 30th.—Wilbur Wright Memorial Lecture, at 6.30 p.m., at the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, W.C.2. Dr. H. Roxbee Cox, F.R.Ae.S., on "The Future of Civil Aviation."

J. LAURENCE PRITCHARD, *Secretary and Editor.*

A THEORETICAL INVESTIGATION OF PLASTIC TORSION IN AN I-BEAM.

By D. G. CHRISTOPHERSON,* Oxford, England.

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The distribution of stress in an I-beam in torsion is investigated by a method of successive approximation, and the regions of initial yielding are determined for several values of the angle of twist. Formulas are given for elaborating the methods of Southwell (1)† and of Shortley and Weller (2) in order to facilitate this determination.

The value of the stress-concentration factor in the fillets is found to agree well with results obtained by soap-film tests, and regions of plastic flow approximate closely those observed by MacGregor and Hrones (3) by the use of the etching method.

According to the standard theory, the problem of the torsion of a prismatic bar reduces to the determination of a function such that

$$(\partial^2/\partial x^2 + \partial^2/\partial y^2)\,\phi = -2\,G\alpha \qquad . \quad . \quad . \quad . \quad (1)$$

where G is the rigidity modulus, α the angle of twist per unit length, and ϕ has boundary values everywhere zero

Many writers have pointed out that an approximate solution to this equation may be obtained by transforming it into an equation of finite differences, in which the value of the stress function at any point is obtained in terms of its value at a number of surrounding points. The most usual procedure has been to cover the area under consideration with a rectangular grid,‡ to compute the value of ϕ at the nodes, and to argue that a surface passing through these points will have nearly the same properties as the actual stress surface, *i.e.*, its contours and gradients will give the directions and magnitudes of the shear stresses, its volume being equal to one half the applied torque. In this procedure the value of ϕ is given in terms of four equidistant values by the equation

$$4\,\phi_0 = \phi_1 + \phi_2 + \phi_3 + \phi_4 + 2\,G\alpha h^2 \qquad . \quad . \quad . \quad . \quad (2)$$

where h is the length of the side of any square in the mesh.

Means of obtaining a rapid solution of such equations in bulk have recently been given by Southwell (1) and by Shortley and Weller (2), although the latter confine themselves to the solution of Laplace's equation $(\partial^2/\partial x^2 + \partial^2/\partial y^2)\,\phi = 0$.

They also give an interpolation function in polynomial form

$$\phi = a_0 + a_1 r\cos\theta + b_1 r\sin\theta + a_2 r^2\cos 2\theta + b_2 r^2\sin 2\theta \qquad . \quad . \quad (3)$$

where r, θ are polar co-ordinates and ar, br, constant coefficients for use over any single square of the mesh, which affords an excellent basis for the deduction of formulas given later in this paper.

Southwell's solution, on the other hand, was applicable to Poisson's equation

$$(\partial^2/\partial x^2 + \partial^2/\partial y^2)\,\phi = f\,(x, y)$$

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† Numbers in parentheses refer to the Bibliography.

‡ An exception is Southwell's (1) triangular mesh.

where $f(x, y)$ was any continuous function whatsoever. In making this generalisation some rapidity in the convergence of the solution was lost, but in the paper (1) referred to previously a number of problems were solved, including one which referred to plastic torsion.

This present paper was planned with a view to comparing this theoretical approach to the problem of plasticity with the experimental approach recently presented by MacGregor and Hrones (3). However, it has been found desirable to make use of certain formulas not contained in the earlier paper (1), which, it is believed, increase the accuracy obtainable by the use of a mesh of given size, and thus accelerate the convergence.

It is evident that equation (2) can only be used exclusively when the section under consideration is such that it can be covered by exact squares. For all other sections it is necessary to develop an analogous relation between the ϕ's when the surrounding points are all at different distances h_1, h_2, h_3, and h_4, from the centre, as shown in Fig. 1. This relation is

$$[1/h_1h_3 + 1/h_2h_4]\phi_0 = \{1/(h_1+h_3)\}[\phi_1/h_1+\phi_3/h_3] + \{1/(h_2+h_4)\}[\phi_2/h_2+\phi_4/h_4] + G\alpha \quad . \quad . \quad . \quad . \quad . \quad . \quad (2a)$$

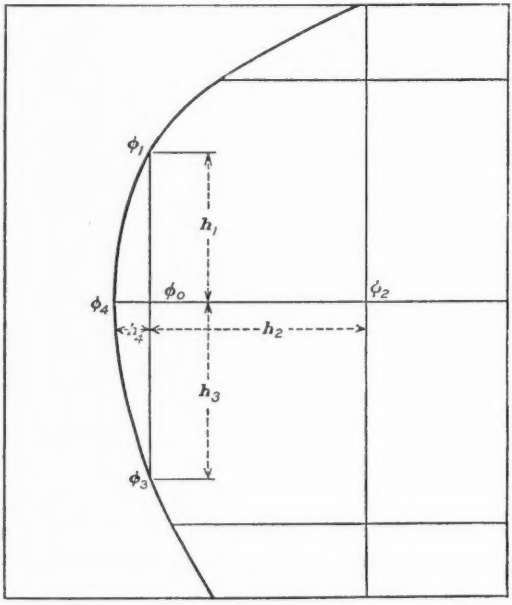

FIG. 1

These are the only equations necessary to determine the required values of the stress function in the elastic problem. From these, with the assistance of the interpolation function given previously in equation (3), the values of the gradients, hence of stresses, may easily be obtained. The volume, hence the torque, comes from the relation

$$\text{Volume of single square} = [(\phi_1+\phi_2+\phi_3+\phi_4)/4 + (\tfrac{1}{6})\, G\alpha h^2]\, h^2$$

When we pass beyond the yield point, however, a different state of affairs obtains. It is first necessary to make a simplifying assumption with regard to the stress-strain curve of the material, and the idealised diagram shown in Fig. 3

is chosen. On this assumption we may make use of the concept of a roof, or limiting value of the stress function, described by Nádai (4). The contours of this roof run everywhere parallel to the boundary of the section and the gradient is uniform and equal to the limiting shear stress.

On this understanding it is easy to compute the values of the ordinates of the Nádai roof over any section, and to make use of the overriding conditions that ϕ must not exceed these values. All that will then be required will be formulas,

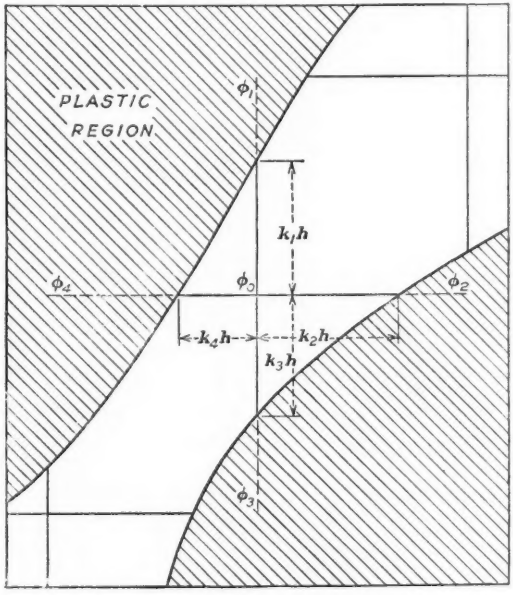

FIG. 2

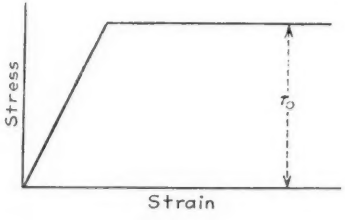

FIG. 3

which provide relations between the ϕ's when some parts of the square under consideration fall in the plastic zone and some (including the central point) in the elastic.

Let us suppose that the limits of the plastic region lie at distances k_1h, k_2h, k_3h, and k_4h, as shown in Fig. 2 so that when the plastic region does not invade the square under consideration at all

$$k_1 = k_2 = k_3 = k_4 = 1.$$

Then the relation which we require is

$$2\{1/(K_1+K_3)+1/(K_2+K_4)\}\phi_0=(\phi_1+\phi_3)/(K_1+K_3)+(\phi_2+\phi_4)/(K_2+K_4)+G\alpha h^2 \quad (4)$$

where $K_1=2k_1-k_1^2$, $K_2=2k_2-k_2^2$, etc.

But for every link crossing the plastic boundary one new variable k will be introduced, so one more equation will be required. This equation is afforded by the fact that at the point of contact the stress surface ϕ is tangent to the roof, which has a known gradient. From this condition we deduce the equation

$$\phi_0[K_1+K_3+2k_1^2]=k_1\phi_3+(2k_1+K_3)\phi_1+(K_1+K_3)\tau_0 h\sin\psi \quad . \quad (5)$$

In this equation ψ is the angle made by the link with the contour line of the roof at the point of contact; τ_0 is the maximum shear stress as indicated in Fig. 3. There will be one such equation for every link crossing the boundary between the elastic and plastic zones, *i.e.*, for every value of k required.

It is not proposed in this paper to enter into detail with regard to the means of obtaining a rapid solution of these equations. The processes used have been described fully in other papers (1, 2). It is therefore only necessary to consider means of dealing with the additional variables k, and the equations giving them.

Fortunately this presents little difficulty, for, if we bear in mind the condition that the stress function cannot have ordinates in excess of those of the roof, and that, when the elastic equations indicate that it does so, the point considered must fall in the plastic region, we may rapidly obtain an estimate of the boundaries of this region. Applying then equations of the type of equation (4) only, we shall be able to determine values of ϕ everywhere, using the assumed values for k. Substituting these ϕ's in equations of the type of equation (5) we can redetermine more exactly the limits of the plastic zone. It will be found that changes in these limits will produce only small or negligible changes in the vertical ordinates of the neighbouring points. That this must be so may readily be seen from geometrical considerations. A small and nearly normal displacement of a surface tangent to a given plane produces a large change in the position of the line of contact.

The whole question of the accuracy and convergence of finite difference equations applied in this manner will not be gone into here. It is hoped that the degree of correlation with experimental evidence which has been obtained will be regarded as providing sufficient justification for the procedures used.

We are now at liberty to proceed to the consideration of the specific problem presented in this paper. Evidently, what in fact we need to determine is the extent to which orthodox (simple) theory is erroneous. For this purpose it is desirable to use as standard of comparison the simplest possible theory of the I-beam—that which assumes the beam to be built up of a number of independent rectangles, each of which is long enough in comparison with its breadth for end effects to be negligible.

On this understanding the relation between torque and twist is

$$T=\Sigma\tfrac{1}{3}b^3lG\alpha \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

where l is the length of a given rectangle and b is its breadth. Also the maximum stress in the section is

$$\tau=bG\alpha \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

Using these relations for comparison, we shall determine first, in the elastic region of the stress-strain curve, (*a*) the actual maximum stress in the fillets for a given angle of twist, and (*b*) the actual torsion modulus of the section; then, second, in the region beyond the elastic limit, (*a*) the extent and shape of the plastically deformed areas, for several values of the angle of twist, and (*b*) the torque-twist relationship beyond the elastic limit. The results are presented in this order.

STRESS CONCENTRATION IN FILLETS.

The maximum stress in the fillets was found to be

$$\tau_{max} = 1.85\ bG\alpha$$

giving a stress-concentration factor of 1.85 when referred to equation (7). The greatest stress occurred very near the point of contact of the inscribed circle, that is, at point A in Fig. 4. It is of interest to compare this result with that obtained by experiment on this section. Using the soap-film analogue, Ehasz (5) obtained a curve showing the value 1.90 for the dimensions here analysed, and claimed an accuracy of 2 per cent. The earlier work of Griffiths and Taylor (6), although it is by no means so complete, appears to indicate a slightly lower value. On the whole, bearing in mind the fact that any errors which exist, either in experimental or in computational technique, are at their maximum in the determination of this quantity, the present author is satisfied with the results obtained.

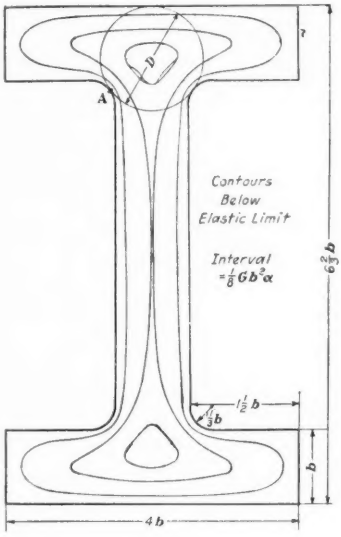

FIG. 4

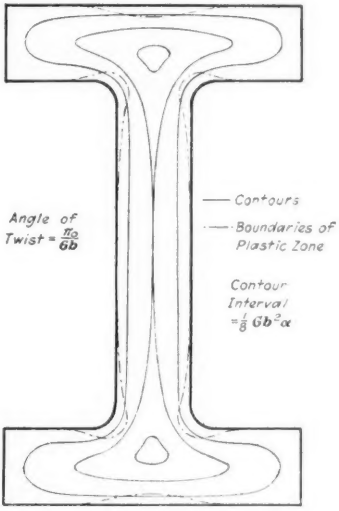

FIG. 5

TORSION MODULUS FOR THE SECTION.

With regard to the torsion constant K in the equation

$$\text{Torque} = \alpha GK$$

the elementary theory as expressed in equation (6) applied to this section gives the results

$$K = 4.222\ b^4.$$

The more complex formula utilised by Lyse and Johnston (7)

$$K = \Sigma\ \tfrac{1}{3}\ b^3 l + 2\ \beta D^4 - 0.42016\ b^4$$

in which the constant β is determined from soap-film experiments gives the value

$$K = 4.748\ b^4$$

and the present investigation leads to the conclusion

$$K = 4.726\ b^4.$$

While it is difficult to estimate the accuracy which can be guaranteed for the first of these two results it is believed that the difference between them (0.5 per cent. approximately) is well within the limits of expected error.

Fig. 4 shows typical stress lines in the elastic region. This figure may be compared to Fig. 9 of a paper by Trayer and March (8), which is a similar contour diagram obtained by soap-film experiment; the similarity between the results of the two processes is very clearly demonstrated.

REGIONS OF PLASTIC FLOW.

The boundaries of the plastic region where determined for an angle of twist

$$\alpha = \tau_0/Gb$$

which, according to the elementary theory expressed in equation (7) would be the twist at the elastic limit, and for angles two-thirds as great and twice as great as this. The results for the first and last of these determinations are given in Figs. 5 and 6.

In the second case the plastic area was found to be restricted almost entirely to the fillets, and an additional diagram was not considered necessary. Fig. 5 shows contours identical with those in Fig. 4 and is intended to indicate the effect of the onset of plasticity on the direction of stress in the fillets. It is noticeable in this figure that, while the angle of twist has been almost doubled since the elastic limit was reached, the plastic zone has not yet covered more than 10 per cent. of the total area of the section.

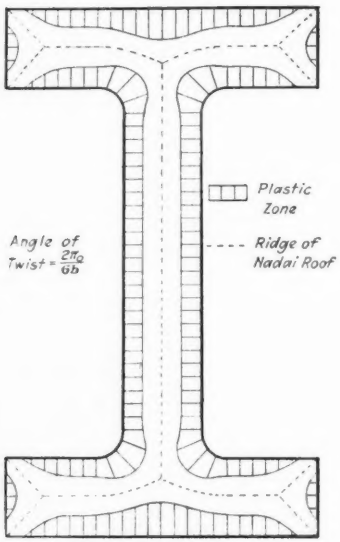

FIG. 6

Redoubling this angle, however, has the effect of producing a very much larger area of plasticity, as is shown in Fig. 6. The results of a test* agree well in general shape with the result we have obtained by computation. In order to estimate the quantitative significance of the comparison, we must first consider the torque-twist relation for the section, which is given in Fig. 7.

We have assumed a stress-strain diagram, shown in Fig. 3, which has no true yield point, in the sense that there is no point on the curve at which increasing strain produces a decrease of stress. It is evident that, on this theory, the torque

* Shown in a photograph not printed.

will increase indefinitely to a finite limit, given by the volume of the Nádai roof. The torque-twist curves given by MacGregor and Hrones (3), on the other hand, do not conform to this condition, indicating that for the material of the specimen (S.A.E. 1112 steel) the assumption of Fig. 3 is seriously in error. It is a matter of considerable interest, therefore, if we can demonstrate that in spite of this the position and size of the plastic region is adequately determined. We may best do this by comparing the value of τ_0 the maximum shear stress, observed in the experiment, with the value which must be assumed in the computation in order to obtain, for the same angle of twist, a diagram identical, as far as one can judge, with the experimental picture.

The actual maximum shear strength observed varied between 48,500 and 53,000 lb. per sq. in. To obtain a diagram identical for identical conditions of twist the assumed value had to be 54,000 lb. per sq. in., but difficulty in measuring from the photograph of the test result may introduce an error of at least 5 per cent. in this value. The agreement may therefore be regarded as satisfactory.

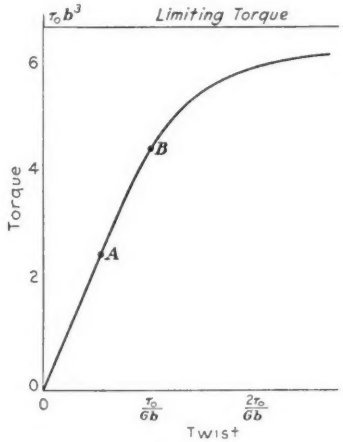

FIG. 7

In spite of failure to agree with results of experiment, Fig. 7 has some additional interest as describing the properties of a hypothetical material. It is noticeable that while the plastic flow actually begins at the point A, very little falling off from the straight-line relation is visible before the point B, which is the elastic limit under the rudimentary theory of equation (7), is reached. At this point also the torque-twist ratio differs by only about 4 per cent. from the value predicted by this theory. It may therefore be argued that for a material of this type under a state of stress such that considerations of fatigue could be neglected, this very simple theory may be applied with much greater success than could be expected. Evidently the errors resulting from neglecting both end effects and fillets tend to neutralise one another to a great extent.

The author hopes that this paper will have some interest as providing additional corroboration for the results obtained by the soap-film analogue, and as helping to demonstrate that the assumption inherent in the Nádai roof analogy does not lead to erroneous conclusions being reached as to the limits of plastic over-strain.

In conclusion he wishes to express his most grateful thanks to C. W. MacGregor and to R. W. Vose for advice and assistance throughout the preparation of this paper.

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A LOW DENSITY MATERIAL FOR AIRCRAFT STRUCTURES.*

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When the all-metal cantilever monoplane brought to a close the era of wood, tubes and fabric for aeroplane structures, the new development opened up broad fields for the improvement of aerodynamic efficiency, with resulting great increases in all-around performance, military effectiveness, and economy of operation.

The all-metal fuselage represented a new type of construction in that the skin formed a shell to replace trusses in carrying the bending loads imposed at the tail in flight and on the ground. The scheme of using a shell to give—at once—structural strength and aerodynamic fairing, previously accomplished by two elements, appears to be economical and sound. If the labour now needed for the fabrication and assembly of the multiplicity of internal members is to be eliminated the stresses must be taken in the skin and the principle should, if practical considerations permit, be extended to include the wing and fixed tail units.

The material used for the reinforced monocoque fuselages has been aluminium-copper alloy sheet so treated as to have favourable relationship between tensile strength and specific gravity.

We know that a structure designed to resist bending must be capable of taking stresses in compression on one side and in tension on the opposite side. In almost every important region in aeroplane fuselages and wings the critical consideration for structural design is the ability to resist stresses in compression. Thin sheet is inherently an inefficient medium for this purpose. A plate in which the ratio of length in the direction of the applied compressive load to the thickness of the plate is high, buckles under compression and, after buckling, is incapable of supporting a load of any magnitude. The deflection in buckling under a given load varies inversely as the elastic modulus of the material, and by the basic theory of moment of inertia, roughly, inversely *as the cube of the thickness* of the material. Hence, duralumin, with specific gravity 2.8 and Young's modulus 10,400,000 lbs./sq. in., has, in the form of an unsupported thin plate of given weight per unit area, 7.65 times the buckling stiffness of a plate of steel having specific gravity 7.85 and elastic modulus of 30,000,000. The elastic modulus is important, the *thickness very important*, and the *strength of material is of practically no importance*. The superiority of duralumin over steel under such conditions is due primarily to its comparatively *low density* which permits, roughly, three times the thickness for the same weight per unit area.

And yet the specific gravity of duralumin is so high and the thickness of shell so small, for reasonable weight, that the skin must be supported against buckling under compression by reinforcing stiffeners. These are attached inside the shell by rivets in sufficient number to insure that each stiffener in combination with the adjacent skin will support a proper share of the load. Closely spaced rivets are also necessary for attaching transverse frames to the skin and to the longitudinal stringers referred to, and also along the joints of the adjacent duralumin panels which are, when assembled, of comparatively small length and width, and hence many in number.

Through the development and use of such production equipment as zinc alloy dies used with air drop stamps, for forming sheet where shrinking is required; heavy hydraulic presses with rubber pads for parts which do not require shrinking;

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the use of air power vertical spindle radial arm routers for cutting and finishing the edges of many sheets at one time; the elimination of the necessity for heat treating or ice preservation of small rivets; the substitution of electric spot welding on non-structural parts; better jigs and fixtures and the use of radial air swinging-arm drills for gang-drilling rivet holes; together with great ingenuity in the engineering layout department to throw a greater and greater proportion of riveting to the bench and less and less on assembly; our manufacturers have gone far toward reducing the time, and labour cost, of production of the all-metal aeroplane.

Nevertheless, some of us became convinced a few years back that, even assuming that high strength aluminium products could be made available in sufficient quantities and at reasonable cost, any type of structure which demanded such a multiplicity of reinforcing parts and so many thousands of rivets did not constitute the best final answer for rapid and inexpensive production. Regardless of cost, and even assuming an unlimited number of skilled workmen, it seemed to be a physical impossibility to find sufficient space around aeroplane assemblies for men to work, to insure rapid production.

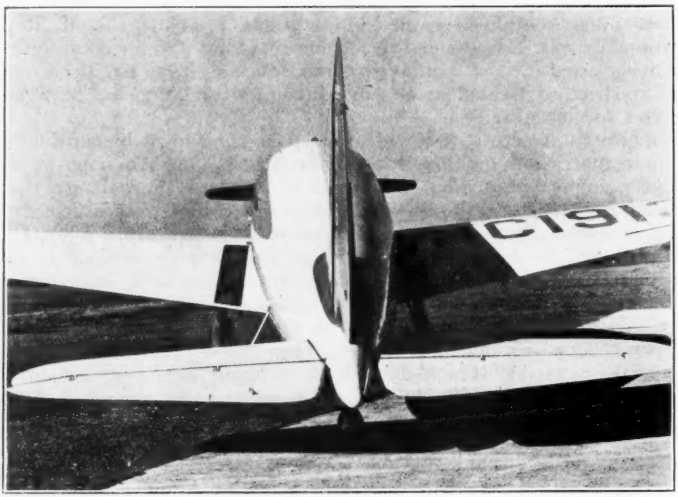

FIG. 1.

Clark Model 46 five-seater aeroplane with fuselage of Duramold.

We became pretty thoroughly convinced that a war might progress so far against us that a large percentage of our aeroplane factories, located as they are, might be incapacitated before we could turn out enough aeroplanes for pilots' training, to say nothing of those for military operation.

Now all these stiffeners and all these rivets are necessary because the metal shell is so thin, for reasonable weight, that it cannot support stresses in compression without them. A *thicker* shell, perhaps one four or five times as thick, might be sufficiently stable against buckling, without reinforcing stringers to gain some of the real strength of the material. Of course, if the weight of the shell is to remain about the same, the *density of the material* must vary inversely as the *thickness* and, for proper structural integrity, the elastic modulus under compression, and the tensile strength, must be satisfactory.

But where to find such a material?

Certain synthetic resins in solid form, such as those of the phenol-formaldehyde family—bakelite—reinforced during the moulding operation by fabric, cord, or other media, have been considered. The density (S.G. 1.37) is so high that the shell wall is too thin without additional reinforcements. The elastic modulus in compression is too low, 600,000 lbs./sq. in. The material flows, creeps and takes permanent deformation under heavy stresses. In some forms it tends to become brittle at very low temperatures. Moulding units of such nature as to insure accurate uniform thickness of a shell the length of an aeroplane fuselage might be prohibitively expensive, if not impossible, and hence a fuselage or wing shell would have to be assembled from a number of small panels.

Moulded vulcanite, expanded under heat to allow a multiplicity of nitrogen bubbles to form—a process analogous to that of the working of yeast in bread dough—has been suggested. It seemed possible to obtain a density perhaps as low as 0.1 with such material. Because of great thickness (" bulk ") buckling troubles would disappear. However, we have yet to learn of such a material having reasonable strength, elastic, and durability properties. It is like balsa wood.

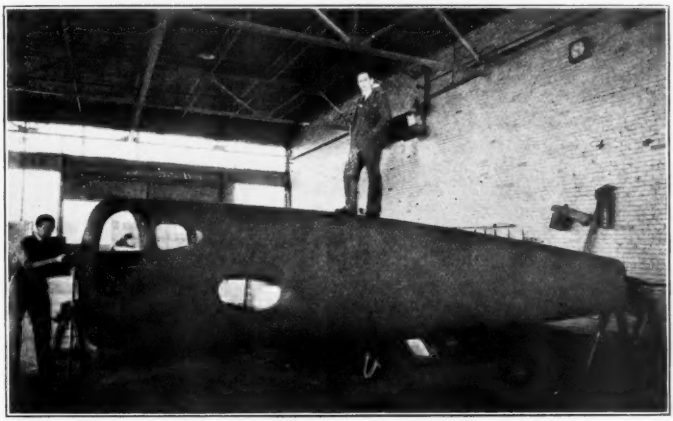

FIG. 2.

Clark Model 46 five-seater aeroplane, Duramold fuselage.

Wood in simple, laminated, and " plywood " form had been used throughout the world in aeroplane structures and found to be utterly unsatisfactory. Under various and varying climatic conditions wooden parts suffered from shrinking, swelling, warping, honeycombing, waving, sogginess, peeling of layers of veneer, separation of glued joints, checking, splitting, increase in weight, and from rapid and serious deterioration from dry rot, various kinds of mould and other kinds of attack by fungi, bacteria, ants, termites, etc. In simple form wood is not a homogeneous material, and unless prepared in such way as to permit complete inspection we could never be sure of freedom from imperfections and of uniformity as to mechanical characteristics.

However, certain species and grades of healthy straight grained wood, because of the fine natural cellular structure, have very favourable relationship between tensile strength and specific gravity—excellent elastic properties permitting the material to be stressed almost to the point of rupture without permanent deformation—the material is inexpensive, and *it is of low density*.

Having in mind the paramount value of this last characteristic we felt, even after bitter experience with wooden aeroplanes across so many years, that if

some method could be devised to inspect the material thoroughly—to insure uniformity in characteristics—and *to preserve* the fine natural, initial properties against deterioration or change in dimensional form, without material increase in density, we would have at least one answer to the problem. By far the most difficult part of the problem has been that of preventing absorption and desorption of moisture in various and varying climates, and the prevention of attack by moulds or fungi. The basic answers to the problem came from the Bakelite Corporation and the Haskelite Corporation. It is comparatively easy to insure uniformity by proper inspection and lamination of the wood in thin veneer form.

Several attempts, some apparently quite successful, have been made elsewhere to reduce the hygroscopic characteristics of plywood and laminated wood to such a degree as to insure against unreasonable taking on and giving off moisture, with resulting change in physical characteristics, weight and dimensional form. These, however, were accomplished by *such increase in density* as to defeat the primary objective—the development of fuselage and wing shells sufficiently strong and rigid without a multiplicity of additional reinforcements. The augmentation of the elastic modulus has yet to approach the increase in the square of the relative density.

A material which we have named "Duramold," having specific gravity which may be accurately controlled within 3 per cent. ±, within a range from 0.5 to 0.9, has been developed. Within this range, the strength and elastic modulus vary, roughly, as the density. In its final form this material is sufficiently non-hygroscopic and free from attack by fungi or moulds and other kinds of deterioration to answer all practical requirements of aeroplane service operation.

Specimens, having ratio of edge area to total area thousands of times as great as the ratio that exists in aeroplane shells, show an increase in weight of less than one per cent. after seven weeks of complete immersion, with negligible change in dimension, no deformation, and no change in physical characteristics.

Duramold is not isotropous, as is shown in the following table (Table I) which gives a few of the important physical characteristics of Duramold in four of its many forms.

TABLE I.

Values (approximate) given in following table are in pounds per square inch divided by (1,000 × specific gravity of material).

Type of Duramold.	Direction of Applied Load.	Tension.	Compression.	Young's Modulus T. & C.
I	Optimum	25.75	13.95	3,060
I	90° to optimum ...	4.72	7.70	714
II	Optimum	22.73	13.03	2,730
II	90° to optimum ...	7.75	8.60	1,053
III	Optimum	19.69	12.08	2,380
III	90° to optimum ...	10.80	9.51	1,395
IV	Optimum	16.75	11.22	2,040
IV	90° to optimum ...	13.87	10.40	1,732

Shear (optimum) 10.4.

The anisotropy of Duramold is not a disadvantage from the practical structural standpoint. In a cantilever wing, or in a fuselage, the maximum stresses in compression and in tension, in a spanwise direction for the wing, and in the direction of the axis of the fuselage, in the regions farthest removed from the neutral axes in bending, are of many times the magnitude of the stresses in a direction normal to these axes.

In resistance to fatigue—based on allowable stress—for equal weight per unit area—Duramold is about 50 per cent. better than 17 ST Duralumin.

Having no hysteresis within the proportional limit which, in tension, is practically the same as the ultimate strength—there is no creep.

It will be noted that the specific tenacity of Class I Duramold is about the same as that of 202,000 pound steel. However, this is not of great practical importance inasmuch as the *density of the material* (in an unreinforced shell) *and the elastic modulus are the only characteristics which enter into the structural design calculations of almost all the critical parts of wing and fuselage shells.*

When considering monocoque structures—inasmuch as strength in compression is of such importance—the strength of a round cylinder under compression loads parallel to the axes of the cylinder is a valuable index. For purposes of comparison George Allward, our chief engineer, has calculated the strength of four cylinders of different types of construction. In all cases the diameter is 60 in., the weight per foot run is constant, and the spacing between transverse frames, or rings, is 30 inches. The basis for comparison is a smooth skin aluminium alloy (17 ST) cylinder with skin 0.032 in. thick reinforced by " flanged Z "

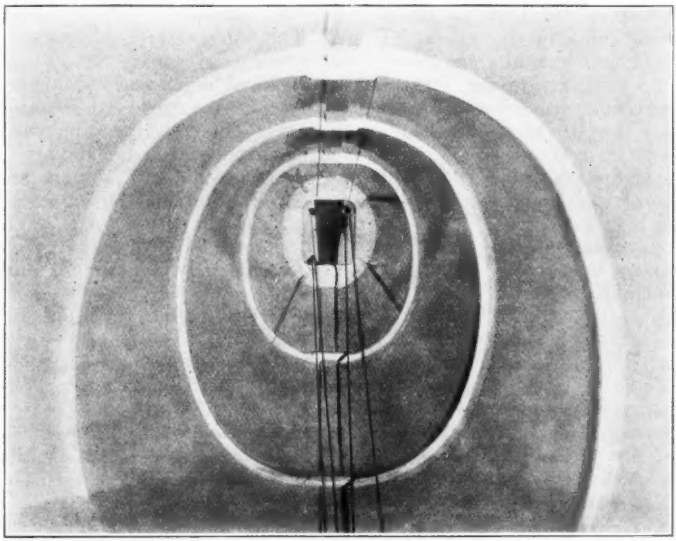

FIG. 3.

Clark Model 46 five-seater aeroplane, fuselage interior.

longitudinal stringers $\frac{7}{8}$ in. by $\frac{1}{2}$ in. by 0.050 in. with spacing of 6 in., giving a total stiffener area of 3.23 in. He calculates that such a reinforced metal cylinder would support a load of 63,000 pounds. An unstiffened aluminium alloy cylinder (of same weight per foot run) would support 30,000 pounds. A cylinder of reinforced synthetic resin (bakelite with fabric or cord) would support 8,000 pounds. A Duramold cylinder of type between Classes II and III will support 113,000 pounds—14.1 times as much as the plastic cylinder and 80 per cent. more than the reinforced duralumin cylinder.

It has been noted that the public press calls an aeroplane which has been undergoing service tests for a year and a half, the fuselage of which is of Duramold, a " plastic " aeroplane. I would refuse to fly in one such. I should require, of the material from which the vital structural parts are formed, a reasonable degree of resistance to flow, a proper ratio of elastic modulus to density, and no permanent deformation under severe loads.

The material will not support combustion and, for given weight per unit area of shell, will support loads after a fire many times better than duralumin. However, this is of little practical importance. It is usually the fuel fire which does the damage.

It is not subject to corrosion.

The energy absorbing characteristics are excellent and the damping of vibration is about five times better than that of metal.

The finished external surfaces are smooth, and calculations, based on wind tunnel tests at fairly high Reynolds number, indicate that, for a high speed aeroplane having fuselage, wings and fixed tail units of Duramold, in the order of 25 per cent. less power will be required at that given high speed than for an all-metal aeroplane with projecting rivet heads, lap joints, and the inevitable waves and wrinkles which are present in flight and/or after service in an all-metal aeroplane.

Duramold has been tested against sharp temperature changes. Panels were soaked in water for two hours at a temperature of $+140°$F. and immediately put in an atmosphere of $-70°$F. During and after repeated cycles there was no sign of weakening or deleterious change. The same tests were made with dry panels with similar results.

While no icing conditions have been encountered in flight Duramold, because of extreme smoothness and its characteristics of absorbing and desorbing heat very slowly, and its high heat insulating properties, should be safer than metal.

The material is not, of course, suitable for such parts as landing gears or control systems. With proper tooling the capacity in the United States for production of such parts in machine shops and foundries has no immediate limit. Neither is it proposed, at the present time at least, that it be used for elevators, rudders, ailerons, cowling and fairing pieces. Non-structural parts which do not demand a multiplicity of riveted reinforcements may be stamped out rapidly from duralumin.

It is suggested, however, that the " neck of the bottle " in rapid production lies in those parts which require so many rivets—fuselages, wings and fixed tail units; and it is for these parts that Duramold may be substituted, thereby not only affording great reduction in production time and cost, but also releasing the workmen, now used for these parts, for other activities.

Concurrently with the development of the material and of the technique and apparatus for producing Duramold parts it has been necessary to evolve new principles of structural design in order that the material may be disposed and utilised in the most effective manner.

Unfortunately, details regarding the basic materials, process and apparatus may not be divulged at this time. Bakelite in various forms plays a large part. Certain delicate combinations of heat, pressure, time, and thermo-setting resins are essential. There is practically no change in moisture content throughout the moulding operation. A complete half-shell of length up to 40 ft. and area up to 500 ft. may be formed, with smooth, permanent, simple or compound curvature, in the same quick and simple operation as that which permanently unites the various basic elements of the shell.

"BUNA" SYNTHETIC RUBBER.*

By E. KONRAD (I.G. Farbenindustrie A.-G., Leverkusen).

Rubber is an indispensable material for the German industry. The yearly consumption is at present about 100,000 tons. For thirty years the German chemical industry has studied the problem of synthetic rubber for engineering purposes, but it has only been in the last few years that the difficulties have been successfully overcome.

CONTENTS.

I. Properties of rubber as a material.
II. Synthetic methods for the production of rubber.
III. Properties of Buna.

Natural rubber has been known for a long time. But it became a technically valuable material only after the discovery of vulcanisation. The development of the modern motor car would have become difficult if the rubber tyre had not have progressed as well. To-day the technical use of rubber is growing. More and more designers are making the best of the novel properties of soft rubber as a constructional material.

This development is best reflected in the world's consumption of rubber. At the beginning of our century only a few thousand tons of natural grown rubber were marketed. Later it was found economical to cultivate rubber in East Indian plantations. In 1906, 66,000 tons were consumed, and to-day the world's consumption is more than 1,000,000 tons annually, of which 100,000 tons are consumed by Germany.

The indispensability of rubber for the German industry and the monopoly of the producers give to the raw material an increasing economical and political importance. In a period which is full of economical unrest and of import difficulties, a Germany which has become conscious of her own strength could not remain dependant on foreign countries for such an important material.

Thirty years ago the German chemical industry began to tackle the problem of the synthetic rubber in a broad way. But it has been only during the research work that the difficulties of the problems involved were fully realised.

I. PROPERTIES OF RUBBER AS A MATERIAL.

In order to make the problem fully understood something must be said with regard to natural rubber as a material. The raw rubber itself has no valuable properties whatsoever. It becomes stiff when cold and it is soft and sticky when heated or subjected to continued mechanical treatment. For direct engineering purposes such a material is useless. The rubber manufacturing industry transforms the crude rubber by rolling and kneading (the so-called masticating) into a plastic and mouldable condition. But the technically valuable properties of the rubber are only developed after vulcanising. This process means the chemical association of the rubber molecules with sulphur. The resulting properties vary in accordance with the amount of sulphur which is being incorporated. A content of 1-5 per cent. sulphur results in soft elastic rubber, excelling by its high

* Translated from "Jahrbuch, 1938, der Deutsche Luftfahrt Forschung."

strength, its capability to expand and its elasticity; 15-30 per cent. sulphur content gives solid rubber having a high strength, small deformation and excellent electrical qualities. Between these a range is found which is not technically important.

Further, it may be mentioned that to-day, besides sulphur, other ingredients have become essential for the development of the more important elastic rubbers. Especially there is a kind of soot, the so-called active carbon black which imparts to elastic rubber high resistance against frictional strains and against tearing. In the cover of a modern motor car tyre, for instance, about 40 per cent. of this so-called filling material is incorporated. Together with the addition of carbon black, immediately after the world war, vulcanisation accelerators and anti-oxidants of age were introduced. These ingredients have become very important for the development of rubber qualities, and this has become evident in the extraordinary improvement of motor car tyre performances.

A synthetic material should permit mixing and moulding similar to the methods employed in the rubber manufacturing industry, it should allow vulcanisation, and the properties in the vulcanised condition should at least approach those of natural rubber.

It has been the combination of these requirements which has made it so difficult to solve the problem of a synthetic rubber.

II. Synthetic Methods for the Production of Rubber.

The *first period* of the efforts for the creation of a synthetic rubber were the years between 1907 and 1919. The price of rubber on the world market had a rising tendency at the beginning of the research work, caused by the increasing consumption. While for a kilogramme RM. 10.— were paid in 1906, the price rose to RM. 28.— in 1914. In view of these prices a synthetic product seemed possible on an economic basis.

At the beginning of 1914 the research work was already so far advanced that the so-called *methyle-rubber* could be made available as an " Ersatz " product for war purposes, in order to encounter the scarcity of rubber caused by the blockade. This synthetic rubber permitted the manufacture of a first class solid rubber which was extensively used for the manufacture of battery boxes on board submarines. But the elastic rubber made from methyle had an insufficient strength; it was like leather and not elastic enough.

After the blockade had ceased and natural rubber was being imported again, the production of methyle-rubber at Leverkusen was discontinued. As a result of this activity, however, the discovery of the accelerators of vulcanisation and of the anti-oxidants of age remained. This proved afterwards of the greatest importance for the development of the natural rubber manufacturing industry and for the technical improvement of soft elastic rubbers.

The second period of the synthetic rubber development set in in 1926. During the post-war time the chemistry of acetylene and its derivatives became technically more developed. Therefore, the possibility existed of obtaining in a simple and inexpensive way the basic materials required for synthetic rubbers. Again research work was started by several I.G. Farben factories and a large staff of experts.

The different butadienes were first considered as suitable elements for the production of rubber. On account of our experience gained during war, dimethylbutadiene was eliminated immediately. After two years of research work the decision was in favour of butadiene. The element isoprene which forms the basis of the natural rubber was left out of consideration, because it did not allow building up the better kinds of rubber than was possible with butadiene. Otherwise, butadiene was technically easier and cheaper to obtain from acetylene as a

basis. And as acetylene can be produced from lime and coal by way of calcium carbide, the basic raw materials at our disposal were unlimited.

Years of indefatigable and often dangerous work carried out by a large staff of chemical scientists and engineers were necessary in order to settle the various steps of the synthetic procedure. The processes employed can be considered peak performances of the modern technique of chemistry, making the widest use of catalytical and continuous methods. Butadiene is produced from acetylene in four steps by way of acetyldehyde, aldole, butylenglycol. It is a gas which can easily be liquefied at $-5°C$. or at normal temperature under pressure.

The next step was to treat the butadiene molecule in exactly the same way as single bricks are employed, and to build up from it the large edifice of rubber. The chemist calls such a procedure " *polymerisation.*"

Now the butadiene has to be considered a very small brick. The word " brick " seems to be the right analogy of the possibilities which are incorporated in butadiene. In exactly the same way as the most varying architectures can be created from one and the same sort of brick as the basic element, the element butadiene gives the chemical possibilities for combinations of a large variety of molecular structures. If we stick to our comparison with architecture, such a combination of butadiene molecules may be compared with, for instance, a long or a short or a small bungalow or even to a modern sky-scraper with many floors and with a complicated interior construction. In accordance with this, the physical and technical properties of the corresponding polymerisates will be very different with such a possible variation in structure.

Now butadiene gas can easily be polymerised to fluids of low density, to tough oils and to solid bodies. Again, within the range of rubber-like materials numerous derivations were possible. The problem was to obtain by syntheses the technically most valuable structures.

Our research work dealing with the constituency of natural rubber had proved that with this material the brick isoprene was connected together to long thread-like fibre structures of many thousand times the length of a single molecule.

Now it would be a mistake to think that in a lump of rubber stretched-out molecular threads are existing. One has to assume these being knotted together, so that a slipping of one against another is impaired. By the use of force, however, the thread-like molecules do slide against another, *i.e.*, rubber is plastic and mouldable. As an effect of vulcanisation, the threads get firmly linked up with another, thus forming the shape of nettings. Then a displacement is only possible within certain limits; the plastic rubber has become elastic rubber.

The polymerisation chemists were thus facing the problem of the discovery of methods for the control of such a thread-like molecular construction with butadiene. Previous research was not available. The progress of our knowledge into the finer mechanics of the structural possibilities of complicated molecular compounds is, therefore, a most remarkable achievement, besides the development of the industrial production of butadiene. This achievement is significant for the second period of the development of synthetic rubber and has resulted in the *Buna* rubber.

A number of processes are known by means of which certain combinations of butadiene molecules can be obtained. A simple heating of butadiene at high temperature results after some months' time in a material which is similar to rubber. Metallic sodium combines with butadiene quickly.

If liquefied butadiene is mixed with a solution of soap in water, a milky butadiene (*emulsion*) is formed. In this emulsified form butadiene polymerises quickly. The result is a rubber milk (latex) which looks exactly like the natural latex obtained from rubber trees in tropical countries. Obviously the processes leading in the plants to the formation of natural latex and those which underlie

the emulsificated polymerisation of butadiene are quite different ones. It is remarkable that chemical research comes so near to the same final chemical structure, the latex, as nature.

During the tedious systematic research with polymerisation certain chemicals were discovered which act as accelerators of the polymerisation, further, one found chemical agents which allow control of the structural association of butadiene molecules in a specified direction and, at last, processes which favour the formation of the required size of the molecule.

To-day, the I.G. Farben is in a position to offer to the rubber manufacturing industry a series of Buna types. Buna 85 is a sodium polymerisate, Buna S and Buna N, now called Perbunan, are emulsificated polymerisates.

III. Properties of Buna.

From the outset it was intended not to copy slavishly natural rubber in its structure and in its properties but to replace it by new materials having improved qualities. Only with such synthetic rubbers was the possibility of achieving economical success guaranteed, in spite of the low world market price for natural rubber—at the end of 1932, natural rubber was sold at RM. 0.30 per kilogramme —and to secure new markets.

Generally, the properties of an *elastic* rubber are defined by its ultimate strength, the expanding deformation up to the rupture and by the rebound elasticity. Table I shows that the strength of Buna in tension is superior to natural rubber.

Table I.

Physical Properties

(Carbon black mixtures of synthetic and natural rubber).

	Ultimate Strength in tension kg./sq.cm.	Elongation at rupture in %	Load at 300% expansion kg./sq.cm.	Shore hardness	Elasticity measured by means of pendulum hammer test
Natural Rubber	260	600	70	65	50
Perbunan	300	600	90	70	45
Buna S	275	650	80	65	50
Methyl Rubber W	125	500	50	plast.	10

Conversion factors : 1 kg./sq. cm. = 14.22 lbs./sq. in.

Table II.

Ageing.

Geer test (70°C. hot air). Carbon black mixtures.

The three figures in each column indicate: Ultimate strength in tension (kg./sq. cm.), elongation in per cent., load at 300 per cent. expansion in kg./sq. cm.

	not aged			8 days			16 days			32 days		
Natural Rubber	260	600	60	245	550	90	210	500	95	160	350	95
Buna N	290	560	90	280	530	100	280	450	130	260	400	140
Buna S	270	705	55	250	650	52	240	600	55	225	575	65
Buna 125	200	750	55	190	725	55	180	650	60	170	625	65
Buna 85	175	700	50	170	675	52	165	650	55	155	600	65

Buna kinds are superior in *ageing* qualities (Tables II and III). With natural ageing, the loss in quality is caused by continued storage under absence of mechanical strains. In a laboratory, this resistance against ageing is commonly

being tested by means of the influence of raised temperatures (Geer test) and by storage in an oxygen atmosphere (Bierer-Davis test).

Further, Buna is less sensitive against the formation of so-called light tears than natural rubber. Many rubber components, especially rubberised fabrics (protective clothing, rain coats, folding boat skins, etc.), are usually prematurely destroyed by the influence of the atmosphere and of light.

At higher temperatures, natural rubber has but a limited life. Even with the so-called " heat-resisting " mixtures made in accordance with the latest practice, a continued temperature of more than 90-100°C. is not permissible. Above this temperature limit the best natural rubber quickly decomposes. Elastic rubber made of Buna is more heat resisting as well in steam as in hot air (Table IV).

TABLE III.

AGEING.

Oxygen under 21 at pressure at 60°C. Carbon black mixtures.
The three figures in each column indicate: Ultimate strength in tension (kg./sq. cm.), elongation in per cent., load at 300 per cent. expansion in kg./sq. cm.

	not aged			8 days			16 days			32 days		
Natural Rubber	260	600	60	100	350	55	70	300	45	50	200	54
Buna N	280	650	70	270	650	70	270	600	80	250	600	100
Buna S	260	600	60	250	600	80	240	600	90	230	600	100
Buna 115	205	700	60	200	700	60	190	675	70	180	650	80
Buna 85	170	650	50	165	650	55	160	625	60	150	620	70

TABLE IV.

HEAT RESISTANCE.

Samples heated in steam of 4 atmospheres (151°C.).

	Ultimate Strength in tension kg./sq.cm.	Elongation at rupture	Load at 300% expansion	Shore hardness	Rebound elasticity by means of pendulum hammer test
		NATURAL RUBBER			
Untreated	180	590	52	55	56
5 days	105	665	18	43	46
10 days	65	620	15	43	42
15 days	60	570	13	41	36
20 days	55	550	12	40	30
25 days	50	530	11	38	27
		BUNA S			
Untreated	170	630	44	55	50
5 days	165	560	64	59	50
10 days	145	480	73	63	50
15 days	140	425	89	68	50
20 days	125	400	92	72	50
25 days	115	350	95	75	52

HEAT RESISTANCE.

Samples heated in hot air of 150°C.

		NATURAL RUBBER			
Untreated	180	590	52	55	56
12 hours	125	510	50	49	43
24 hours	50	420	31	45	34
48 hours		hard and brittle			
72 hours		" "			
		BUNA S			
Untreated	170	630	44	55	50
12 hours	117	330	110	69	45
24 hours	95	220	—	72	40
48 hours	75	125	—	73	38
72 hours	65	110	—	75	35

This table shows that the strength of Buna in tension under the influence of heat does not decrease to such an extent as natural rubber. While natural rubber tends to soften and to become inelastic, Buna inclines to harden, to become more taut and more elastic.

Of the engineering applications of Buna may be mentioned that the properties are valuable for the manufacture of heating pipes, radiator hoses for glycol and glycerine flowing at a raised temperature, of gaskets, belts, buffers, conveyor belts for hot parts, etc.

Another special quality of Buna is its high resistance against wear. Admittedly, a modern tyre cover mixture incorporating active carbon black has a wear resistance which is several times higher than that of steel. Yet the Buna types

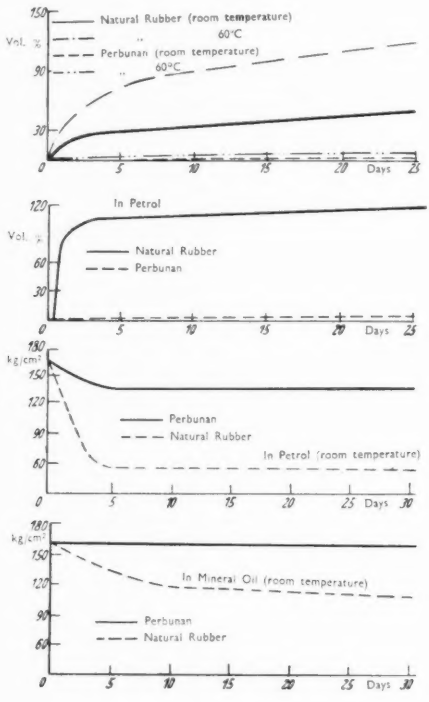

FIG. 1.

Increase of volume and strength of natural rubber and synthetic rubber.

designated by letters are still considerably superior in this respect. The highest resistance against wear is shown by *Perbunan* after this rank Buna S and Buna 85. If one assumes the wear of a first class tyre cover mixture made of natural rubber equal to 100 units of worn area, under equal conditions the wear with Perbunan will be only 60 units, with Buna S, 75-80 units, and with Buna 85, just as much as with natural rubber. As a result, it is possible to manufacture from Buna rubber qualities which with regard to wear will last nearly twice as long as the best mixtures incorporating natural rubber.

So-called *oil-proof* vulcanisates of natural rubber swell in a short time to many times their original volume by soakage, as soon as they are in contact with organic soaking materials, and they lose practically all their mechanical properties; strength, structure and wear resistance deteriorate very quickly (Fig. 1).

The behaviour of Perbunan is quite different, while the other Buna types are in this respect like the natural rubber. Only to a negligible extent will vulcanisate of Perbunan swell by soaking up mineral oil, petrol, organic oils and fats. The increase in volume amounts to a few per cent. (Fig. 1). Practically, the small quantity of soaked-in material does not affect the mechanical properties. Elastic Perbunan rubber, however, swells considerably in aromatic and chlorate hydrocarbons such as benzole, loluole, carbon tetrachloride, trichlorethylene. Solvents of this kind, however, are not very important for engineering use. With fuel mixtures such as petrol-benzole vulcanisate of Perbunan is still superior to natural rubber.

For these reasons it is possible to employ the valuable elastic properties of elastic rubber for such engineering purposes for which hitherto natural rubber had to be excluded. Examples are materials for hoses, shock absorbers, washers and sealing strips, wiring cables, diaphragms for pumps, conveyor belts, transmission belts.

Among the oil-proof rubbers, a synthetic rubber *Duprene* or *Neoprene* is being marketed in America by the Du Pont firm. The resistance of Perbunan against oils is superior to that of Duprene.

In this connection it may be mentioned that the manufacture of an oil-proof elastic material has been started on quite different lines. We have succeeded in marketing products which, with regard to high rubber-technical properties, are not quite up to the standard of Perbunan, but the resistance of which against swelling is superior, thus offering an excellent material for certain special purposes.

With the Buna types designated by a figure, a solid rubber can be manufactured which is better heat-resisting and more resistant against chemicals than hard rubber based upon natural rubber.

As the structural principles of Buna are not like those of natural rubber, its behaviour during the handling by the rubber manufacturing industry is somewhat different. Generally, however, the same manufacturing methods and mixture ingredients can be employed with Buna as hitherto customary with natural rubber. At the same time as the research work went on with the basic materials and with the polymerisation, the rubber experts succeeded in creating suitable mixtures and their industrial handling up to the final product.

From the beginning the greatest stress has been laid upon the manufacture of car tyres. Products of this nature require a combination of the optimum qualities of the material. As soon as we succeeded in developing Buna tyres which were superior to tyres made from natural rubber, the experience gained could be employed immediately for every other branch of the rubber industry. The *Buna tyre* of to-day which is being manufactured by all German tyre factories, is in all its properties superior to tyres made from natural rubber. From the beginning, the military authorities have taken part in testing the tyres. Millions of kilometres have been driven with many thousands of tyres.

In Germany, one has taken an interest as well in the synthetic *Duprene* or *Neoprene* rubber made in U.S.A. In spite of all efforts, no satisfactory tyre could be realised with this material till now. The Russian synthetic rubber, too, does not allow the manufacture of serviceable tyres, in spite of all contradictory reports.

Besides the development of a rubber for tyres, we endeavour to find special kinds which will open new ways of industrial employments, and which will meet requirements which hitherto could not be fulfilled with rubber. At Leverkusen a research department exists which is discovering special features of new synthetic

rubber types, and which works in intimate touch with the industry interested in such rubbers.

At present we are in the third period of the synthetic rubber. Since Adolf Hitler came to power the work with synthetic rubber has gained a fresh impulse. At present the production facilities for Buna are being extended in order to guarantee the home consumption of Germany. In connection with this, efforts are being made to introduce the material into the rubber manufacturing industry and to manufacture it for all purposes. The experience gained during the past few years proves that great progress has been made and will be made with such a collaboration between producer and manufacturer.

THE MOUNTING OF AERO ENGINES WITH SPECIAL REFERENCE TO RUBBER AND BUNA MATERIAL.*

By B. STEINBORN (Continental Rubber Compagnie, G.m.b.H., Hannover).

The following remarks refer to the fundamental conditions which have to be considered for the use of rubber for the mounting of engines. It is thought essential that aircraft firms should ask for information with regard to rubber components they intend to use at an early stage of the design so that faulty applications of such parts can be prevented. Figures for the permissible loads and hints for the design of rubber components are given, with special reference to the use of Buna. Some constructional features are discussed as an explanation of the advice tendered to the designer.

From previously published reports it can be concluded that there are clear and accurate theoretical conditions governing the elastic mounting of aero engines. A comparison of the practical solutions, however, proves that the mountings in use differ greatly from one another. One is apt to conclude from this fact that the conditions governing such mounting are not always fully understood.

Our own intensive research in this direction began following requests from the ship building and motor car industries. We arranged the elements of the mounting so that the engine was running either with a speed above or below the critical speed. We also tried to find solutions of our own in view of the circumstance that it was hitherto not stipulated if the aeroplane or the engine designer was responsible for the elastic mounting. But we found this unsuitable because our theoretically appropriate designs proved to be useless for practical adoption. The sizes of mounting blocks for engine mountings below the critical speeds, grew too big, for instance 100 × 80 × 150 mm. in compression or relatively less stressed under shear. The damping elements for mountings, above the critical speeds, however, had to have such a small rubber volume, in order to satisfy a sufficiently high frequency figure in all six degrees of liberty, that one could not assume it to function properly as an elastic mounting under all service conditions. We were unable to lay out designs for which self frequency figures existed between limits given by a defined speed range, because the generating causes and the ranges in which resonance existed were unknown to us. The calculations were made by us by means of the " Waas " method, and we defined a mounting having six degrees of liberty. In spite of the fact that we are fully conversant with the calculation of stationary engines of which we know their moments of inertia about the three axes and their centre of gravity distances relative to the same axes, we are convinced that in aircraft construction the conditions which have to be considered are of such a special nature that only the aeroplane designer can deal with them.

It is for these reasons that we suggest we are approached at the proper time by the aeroplane designer for assistance, *i.e.*, during the design stage, and to obtain for the rubber technological part precise information, especially with regard to the space available (installation sketch), damping travels required for specific loads (load-travel curve) and the distribution of forces at each point of the mounting in question.

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* Translated from " Jahrbuch, 1938, der Deutsche Luftfahrt Forschung."

For the lay-out of an aeroplane design the following figures relating to the strength of rubber components may be given:—

Rubber loaded in compression:—

Normal ... 10-15 kg./sq. cm. (142-214 lb./sq. in.).
In special cases 40-50 kg./sq. cm. (570-710 lb./sq. in.).

Rubber under shear load:—

Normal 3-5 kg./sq. cm. (43-71 lb./sq. in.).
In exceptional cases up to 15 kg./sq. cm. (214 lb./sq. in.).

The maximum values given are only deemed advisable if the deformation is restricted by limiting stops.

The load figures have to be, of course, in every case calculated and scheduled by us but the values given above may be helpful as a general guide. While with rubber an ultimate strength of about 300 kg./sq. cm. (4,300 lb./sq. in.) is obtainable under laboratory conditions, it must be realised that this value is only to be achieved with small test pieces and cannot be related to large cross sections. Because of surface tensions, strained fibre length and especially because of the effective strength of the bonded area, a much lower value is indicated. The safety factors will thus become at the higher strength figures specified or the order of 1.5 to 2.

We should like to recommend relating in future strength figures only to a standard test block, because the ratio of base measurements to heights due to boundary strains is of much importance.

In the specifications of rubber qualities frequently hardness figures desired are given in accordance with the American system, *i.e.*, Shore hardness. It is, however, intended to introduce in Germany the DVM hardness (" Deutscher Verband fuer Materialforschung "). With this test the impressed depth is measured and given as a hardness value in 1/10 mm. A ball of 10 mm. diameter is used, an initial load of 50 gr. and an additional test load of 1 kg. with a testing time of 10 sec. and with a rubber thickness of 6 mm. The Continental Caoutchouc Compagnie is prepared to forward a comparative table giving the hardness values according to the Shore and to the German standard system.

The hardness tolerances of the rubber qualities used are ± 5 per cent. Natural rubber and Buna rubber are available for elastic engine mountings in Shore hardnesses of 33 to approximately 80, corresponding to a DVM hardness of 97 to 28. Some firms have tried to introduce their own hardness figures but attempts of this kind should not be encouraged.

The use of Buna is of special interest for metal bonded damping elements. We have made therefore a great number of tests, and we are now in a position to state that the manufacturing problem is practically solved. However, the particular properties of Buna have to be taken into consideration, and for this reason further development work has become necessary. For instance, the lasting deformation of certain qualities is still too high. Further, the structural strength is not yet as it should be, if the limiting values have to be used. It is, therefore, not considered advisable to enforce by regulations the use of Buna, unless special reasons make it necessary. Otherwise, more damage would be inflicted on the cause of Buna. We are endeavouring to introduce Buna generally as soon as possible but we must conduct careful tests, eventually jointly done with other bodies, before recommending it. We have prepared schedules for the use of the motor car industry after the completion of our own practical tests. According to these schedules tests on a large scale will be conducted by the industry. Afterwards the general introduction will be ruled either specified according to objects or to industry groups. The same principle should be adhered to with rubber components in aeroplane construction.

Comparative tests between natural rubber and Buna showed that the damping qualities are higher with Buna. Contrary to previous customs of the rubber

industry, it seems necessary to specify one or several new quality values in order to define the dynamic behaviour, *i.e.*, figures which depend upon the damping properties (a dynamic constant of rebound elasticity, for instance). The research work done by I. G. Farben (obtaining of hysteresis loops in diagrams) and, independently, of Continental Caoutchouc in order to get values of the relative damping (relation of the interior friction transformed into heat to the energy required for deformation) are providing new and important information. Research work of this nature gives reason to hope that such qualitative values of rubber properties can be collected.

It is possible to-day to use light alloys for the metal bonding of vibration absorbing elements, but in this case the heavier of the light alloys such as duralumin and silumin are preferred. The best bonding values, however, will be obtained with disc plates made of steel or of iron. Methods have been discovered which allow galvanizing light alloys subsequent to Eloxal treatment. This is done by mechanically grinding the spots on to which the rubber has to be vulcanised; after this, the Eloxal treatment required for vulcanisation can follow. In spite of this method, mounting parts made of light alloys, especially those made of the home produced electron metal, are preferred with which the rubber blocks are bonded to thin steel plates, the latter being assembled interchangeably to the main mounting parts made of light alloy.

Special consideration has to be given to the behaviour of rubber under the influence of differences in temperature. This forms at present part of a tedious research work. The damping decreases at higher temperatures (up to about 80°C.) thus influencing the elasticity value. One might neglect this fact, but the changes to be observed at low temperatures cannot be overlooked. At -50°C. stiffness of the rubber may set in. The modern rubber qualities in use for aircraft purposes, however, undergo in the most unfavourable case elasticity changes of but 30 to 50 per cent. Buna can be expected to show a much better behaviour with changes of temperature.

The following points should be considered for the *design* of mounting blocks. In view of mould costs and interchangeability simple parts should have the preference. Sharp edges should be avoided at the metal parts, and all corners should be chamfered. It is advantageous to use thin steel plates which allow for interchangeability and adjustment. Within the rubber the strain should be uniformly distributed. This secures a better resistance against endurance fractures (for instance, a shaft coupling, both discs of which are conically shaped so that the rubber is being supported by these conical parts, instead of being mounted between flat discs).

Arrangements liable to slip as soon as the rubber is being deformed should be avoided as far as possible.

In view of the peculiarities of rubber as an engineering material and because of the relatively high specific loads, it is necessary to incorporate always mechanical safety measures as a precaution, *i.e.*, the designer has to provide for an interlocking catch at the damping elements, which comes automatically into action as soon as the rubber fails as a supporting and connecting medium.

The rubber specialist has several possibilities for a variation of the self frequency. Rubber qualities with different hardness and elasticity may be chosen. Otherwise, the choice is between compression or shear loading, the ratio between compression and shear loading being about 1.7. Further, the ratio between basis and height and the fibre length are of importance. Finally, the specific load acting on an element has to be taken into account; the higher the load, the smaller the " c " value and with it the self-frequency value, within the limits stated above, of course.

Concluding, some practical examples of elastical engine mountings are shown in Fig. 1 to Fig. 6, the design of which is in accordance with the construction hints given.

Fig. 1. The simplest form of an engine mounting, combining compression-shear loading. Because of compression of the outer discs, the damping constant is variable.

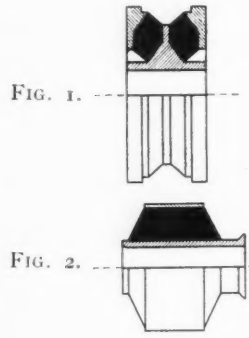

FIG. 1.

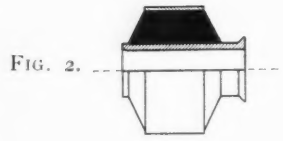

FIG. 2.

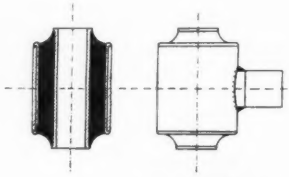

FIG. 3.

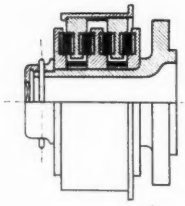

FIG. 4.

Fig. 2. Simple form of a mounting bush. Preferably, the outer liner should be split and made from thin-walled carbon steel tube.

Fig. 3. Often used bush form, usually for radial engines. The outer steel liner is split. During assembly it is pressed into the corresponding bearing bush of the engine mounting and protected by bordering from coming out.

FIG. 5.

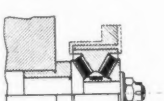

FIG. 6.

Fig. 4. Shear-compression bearing, split up into single ring disc elements. These rings are easily interchangeable and can be supplied with variating damping constants. With the exemption of the thin discs which form the base for the rubber, the mounting is designed for light alloy. The movement is restricted in a radial direction.

Fig. 5. Similar design as shown in Fig. 4, but with an increased axial deflection obtained by an inclined arrangement of the rings. The movement is restricted in a radial direction.

Fig. 6. Simple adjustable bearing with conically arranged ring elements.

ABSTRACTS FROM THE SCIENTIFIC AND TECHNICAL PRESS.

Issued by the
Directorates of Scientific Research and Technical Development, Air Ministry.
(Prepared by R.T.P.)

No. 77. April, 1940.

Interpolation Method for the Calculation of Families of Trajectories and Their Variation with Changes in the Original Ballistic Values. (H. Athen, Z.A.M.M., Vol. 19, No. 6, Dec., 1939, pp. 366-371.) (77/1 Germany.)

For a given resistance function, the solution of the ballistic problem depends on the initial velocity and path inclination. In practice, the problem usually consists of determining a family of trajectories having a constant initial velocity V_0 and to investigate the changes produced by varying V_0 and the external ballistic factors. For this purpose it has been usual to calculate at least 6-8 trajectories for each elevation, and every variation in the ballistic constants introduces a further set of calculations. It is the purpose of the present paper to show how this amount of work can be very considerably cut down. In the new method only two or at the most three trajectories require complete calculation and the constants obtained in this manner suffice to determine the whole family including the effect of variations. The method is based on the well known Popoff solution of external ballistics in which the trajectory is expressed as a function of the original path inclination only. Knowing two trajectories, the family can be determined by interpolation. Amongst the effects of external change, the author gives special consideration to atmospheric changes in temperature with height.

The Development of the Machine Gun. (M. Runnebaum, W.T.M., Vol. 44, No. 2, Feb., 1940, pp. 25-32.) (77/2 Germany.)

The history of the Maxim gun and its use during the war, 1914-18, is reviewed. After the 1914 war, every military state tried to obtain a reliable light machine gun weighing less than 20 lbs. For aircraft use the rate of fire has been increased to the order of 1,000 rounds per minute. Heavy automatic guns of 20-25 mm. calibre, firing explosive shells of 150 gm. for use against tanks, have also received great attention. The firing rate is of the order of 300 rounds per minute and the maximum range 6,000 m.

Machine guns can be classified into the following three groups depending on their principal design characteristics:—

I. Recoil operated with mobile barrel (Maxim and Bergmann).

II. Gas operated (Hotchkiss, Colt, Lewis). In this design, a portion of the explosion gases is tapped off to operate the mechanism.

III. Recoil operated with fixed barrel (Schwarzlose and Bergmann). The gas pressure acting on the base of the cartridge case pushes back the breech and operates the whole mechanism.

It will be noticed that a number of alternative solutions exist. The simplest gun is generally the best since it can be produced in quantity without excessive technical difficulties.

Unorthodox Guns and Projectiles. (P. Chaville, La Science et la Vie, Vol. 57, No. 274, April, 1940, pp. 316-324.) (77/3 France.)

A few of the proposals deserve attention.

Gun with Conical Barrel.—The object of a gradual reduction in calibre as the projectile leaves the gun is to ensure a high muzzle speed at moderate gas pressures. Applied to a 7.7 rifle, the diameter at the bottom of the rifling would be 9.2 mm. for a distance of 500 mm. from the breech. The diameter is then progressively reduced to 7.7 mm. at the muzzle. The bullet is provided with a central groove into which flows the excess metal of an obturator ring as the bore diminishes. It is known that Germany carried out experiments with such a weapon about 30 years ago.

The Electric Gun.—As is well known, an electric conductor in a magnetic field experiences a directing force. In this proposal, the shell consists of a steel arrow which bridges two parallel conductor rails, thus acting as a slider. The arrow is given a translatory motion by the superposition of an electric field. The device was tried by the French Government in the 1914 war and it is stated that speeds of the order of 200 m./sec. could be produced in a steel arrow weighing 50 gm.

Tunnel Projectiles.—Projectiles with a central passage for the air were tried in 1930. The object is to reduce air resistance, but the tests showed no advantage of this design.

Anti-Aircraft Projectiles, Releasing Wired Discs.—This device is obviously inspired by the old Baron gun, which was twin barrelled, two projectiles connected by a chain being fired simultaneously. In the modern version, a normal gun is used, the explosive shell containing a number of discs, each pair being connected by a coil of wire. A simple and more practical device consists of a single coil of wire of great length attached to a small parachute. It is interesting to note that the proposal for an aerial barrage dates back to 1917.

The Possibilities of the Rocket in War. (A. Ananoff, La Science et la Vie, Vol. 57, No. 274, April, 1940, pp. 451-460.) (77/4 France.)

After a brief review of the military history of the rocket, the author deals more specially with modern developments rendered possible by the introduction of liquid and gaseous fuels. The main advantage of the rocket as an offensive weapon is the fact that, being self-contained, it can be launched by means of a very flimsy cradle. The importance of this will be realised when it is remembered that a 6 in. field gun in firing position weighs over 13 tons and requires over one hour's work before it can be shifted. The chief difficulty, apart from corrosion of the nozzles, is to ensure adequate stability during prolonged flight.

Applied to aircraft bombs, the rocket should increase the terminal velocity and hence the destructive effect. It has also been proposed to neutralise the effect of the aircraft speed by applying a reaction to the bomb in the opposite direction. The bomb will now drop vertically and this should simplify the aim. By means of composite rockets, great altitudes could be reached and this is of interest in A.A. defence, since the limit of the usual artillery fire is reached at an altitude of 12,000 m. The rocket, not being subjected to the high pressures of a shell fired from a gun, can be easily adapted to a multitude of purposes, such as containing wires and parachutes or subsidiary grenades for aircraft attack. Finally, if aircraft speeds of the order of that of sound are required, the normal propeller drive will have to be replaced by rocket propulsion.

Fighter Aircraft of To-day and To-morrow. (R. Maurer, La Science et la Vie, Vol. 57, No. 274, April, 1940, pp. 401-423.) (77/5 France.)

In the present-day fighter, the low wing monoplane and the liquid-cooled engine have become practically the standard equipment. There exists, however, still some diversity in the armament question and a multiplicity of light calibre guns (eight machine guns on the Spitfire) is advocated by some, whilst others prefer fewer guns of heavier calibre. The latter alternative has the advantage of giving a better ballistic coefficient and therefore a longer range. It is true that up to now, air fighting to be effective has had to be carried out at ranges of the same order as in the 1914 war. As soon, however, as automatic sights for the heavier guns become available, the longer range weapon may prove superior. Departures from orthodox design, such as the American Bell P. 39 (engine behind pilot so as to improve view) and the Fokker D. 23 (engines in tandem, one behind and one in front of the pilot) have not yet been tried under war conditions. The twin fuselage Lockheed P. 38 appears to be too complicated for handling by a single pilot.

The weak spots of any design can only be revealed by experience in actual fighting. Victory will come to the nation which learns by experience and can adapt its production accordingly.

Future development, in its broad outlines can, however, be summarised very shortly; more horse-power and greater gunpower.

A New Method of Studying the Flow of the Water Along the Bottom of a Model of a Flying Boat Hull. (K. E. Ward, N.A.C.A. Tech. Note No. 749, Feb., 1940.) (77/6 U.S.A.)

A new method of studying the flow of the water along the bottom of a model of a flying boat hull is described. In this method, the model is fitted with a transparent bottom and is divided down the centre line by a bulkhead. The flow is observed and photographed through one-half of the model by means of the diffused illumination from a battery of lamps contained in the other half of the model. Photographs of the flow, particularly of the changes that occur when the step ventilates, are shown.

The results of the present investigation indicate that the method has considerable promise, chiefly in connection with motion picture studies.

The method should prove to be of use in conjunction with studies of bottom pressures by showing the movement of the peak pressure in landings, in rough water, and in porpoising.

Laminar Boundary Layer Phenomena on a Rotating Disc, with Special Reference to Change in Speed of Rotation (Starting and Stopping). (K. H. Thiriot, Z.A.M.M., Vol. 20, No. 1, Feb., 1940. pp. 1-12.) (77/7 Germany.)

The equations of a laminar boundary layer subjected to a centrifugal field of force are established and solved by the method of Blasius. The resultant streamlines are in the form of logarithmic spirals. The theoretical conclusions were checked by photographic records, using potassium permanganate crystals (0.3 to 0.5 mm. diameter) in water contained in a circular dish 900 mm. diameter.

The secondary flow phenomena observed under these conditions have some connections with certain meteorological phenomena (cyclones).

The Theory of the Annular Wing (Nozzle in Free Flow). (H. E. Dickmann, Ing. Archiv., Vol. 11, No. 1, Feb., 1940, pp. 36-52.) (77/8 Germany.)

The author investigates the case of a ring-shaped aerofoil (nozzle) immersed in a known field of flow. The problem is simplified by replacing an aerofoil of this type by a series of ring vortices on the skeleton line of the cross section. This leads to a non-linear integral equation of the first kind having elliptical

integrals as a core. These are expanded in a series of simpler core functions, the first of which is equivalent to a straight line vortex whilst succeeding terms allow for the curvature of the ring. By means of Fourier's series the problem finally reduces to an elementary system of m equations with m unknowns.

The special case where the skeleton of the aerofoil cross section is a straight line is solved as a simple example. It is shown that for the same resultant flow, the circulation round the ring-shaped aerofoil is considerably greater than that round a plain aerofoil of the same cross section. This is due to the fact that the induced velocity associated with a ring vortex falls off more rapidly with distance than is the case for a straight line vortex. In order to obtain a given velocity field, the distribution density of the vortices, *i.e.*, the circulation, must be greater in the case of the annular wing.

Lift and Moment of a Control Surface of Finite Thickness and Negligible Gap. (W. Weinberger, L.F.F., Vol. 17, No. 1, 20/1/40, pp. 3-11.) (77/9 Germany.)

The problem of the two-dimensional flow round control surfaces without gap has been investigated by Glauert for the case of vanishing profile thickness, using the method of line vortices. The results were, however, not in satisfactory agreement with practice and it was hoped by the D.V.L., that by introducing the thickness of the profile into the investigation, a better agreement would be achieved. The author investigated for two-dimensional potential flow the values of the lift moment, normal force on flap and moment of flap using such profiles as lend themselves easily to conformal representation on a circle, and assuming a linear theory as regards incidence and rudder deflection. It was found that the thickness of the profile reduced the coefficient of the flap moment appreciably and brought the results into much closer agreement with wind tunnel measurements. The effect of thickness was, however, negligible in the case of the calculated values for the remaining coefficients of the control surface.

The Velocity Field in the Neighbourhood of a Control Surface of Finite Thickness and Negligible Gap. (H. Menzel-Rogner, L.F.F., Vol. 17, No. 1, 20/1/40, pp. 11-17.) (77/10 Germany.)

The two-dimensional potential flow round an infinitely thin flapped wing can be calculated in a simple manner by using the Birnbaum method of equivalent line vortices. The author extends the case to a finite thickness by utilising the method of conformal representation, the control surface and flap being approximated to by a Joukowsky profile and a linear theory for incidence and flap deflection being assumed. The velocity distribution is calculated for a series of points extending to a distance of $4\frac{1}{2}$ chord lengths. Comparison with the corresponding case of an infinitely thin wing shows that the effect of the thickness diminishes rapidly with distance from profile and does not extend beyond two chord lengths.

Recently Keune (Yearbook of German Aeronautical Research, 1938, Vol. 1, pp. 3-26) has given an approximate method for the determination of the velocity field in potential flow round thick profiles. A comparison at a few check points shows satisfactory agreement with the results obtained by the author by the method of conformal representation.

Lift and Moment of a Flat Plate, Bent at a Short Angle with a Gap at the Corner. (H. Sohngen, L.F.F., Vol. 17, No. 1, 20/1/40, pp. 17-22.) (77/11 Germany.)

The author calculates the lift and moment coefficients as well as the pressure distribution of a simple form of symmetrical double wing, making use of the Birnbaum theory of the equivalent vortex surface. The system of integral equations is solved by a method discussed previously by the author (Math. Zeitschrift,

Vol. 45 (1939), pp. 245-264). The solutions are given in explicit form and an accurate linear theory of the flow angle is accepted. The coefficients of the lift and moment as well as the lever arm of the normal force on the flap at zero deflection are given in pictorial form for value of the ratio (chord of flap)/(total chord) of 0, 1/9, 2/9 and 3/9 respectively. From these figures intermediate values can be obtained by interpolation.

Lift and Moment of an Unsymmetrical Double Wing. (F. Losch, L.F.F., Vol. 17, No. 1, 20/1/40, pp. 22-31.) (77/12 Germany.)

The unsymmetrical double wing consists of two similar symmetrical Joukowsky-Betz profiles, the auxiliary wing being placed below and to the rear of the main surface. The two-dimensional potential flow is calculated by the approximate conformal representation of the field on the exterior of two circles. The pressure distribution on the wing system is calculated for a series of incidences and flap deflections. These distributions are utilised to obtain the coefficients of lift, moment, normal force on flap and flap moment in the linear range of incidence and flap deflection, the results being shown in a series of diagrams.

Flow Round Wings Accompanied by the Separation of Eddies. (C. Schmieden, L.F.F., Vol. 17, No. 2, 20/2/40, pp. 37-46.) (77/13 Germany.)

The flow round wings calculated by the usual method leads in the case of a finite trailing edge to a stagnation point at the rear edge due to the Kutta-Joukowsky condition of flow governing this region.

As a result the theoretical pressure distribution differs markedly from the experimental values in the neighbourhood of the trailing edge.

The author develops an alternative method of calculation in which the rear stagnation point no longer appears.

The stream leaves the rear edge tangentially on the pressure side and a similar tangential separation occurs on the suction side of the profile at a point slightly in front of the trailing edge. Both these limiting stream lines are formed by vortex sheets of equal and opposite circulation and enclose a " dead-water " region, the width of which diminishes to zero with increasing distance from the edge.

The flow in the immediate neighbourhood of the vortex sheet is parallel and of constant velocity and undergoes a sudden increase proportional to the vortex strength on passing through the sheet. The author shows that out of the multitude of possible flows for a given profile at a given incidence, only one flow characterised by a definite breakaway point in the suction side leads to the condition of constant speed along the trailing stream lines together with a dead water region which disappears at ∞. The calculation is carried out first explicitly for the simple case of a flat plate and then extended to a form of modified Joukowsky profiles which are amenable to simpler treatment.

The resultant force on the profile is finally calculated from the pressure distribution and leads to a pure lift force as required by theory.

Trigonometric Series Solution of the Prandtl Equation for Circulation. (K. Jaeckel, L.F.F., Vol. 17, No. 2, 20/2/40, pp. 47-53.) (77/14 Germany.)

The author demonstrates that the basic Prandtl equation for the finite wing in the form of an integral-differential equation is fundamentally no more limited in its application than the corresponding solution based on potential theory. By a suitable extension of the integral giving the induced velocity at the wing due to the presence of the vortex band, both methods of treatment are shown to cover the same range. The use of Fourier series for the evaluation of the Prandtl integral-differential equation is therefore also permissible in the case of a discontinuous distribution of angle of incidence or length of chord.

Intensity of Sound Emitted by Various Profiles Moving at High Speed. (W. Holle and E. Lubcke, L.F.F., Vol. 17, No. 2, Feb., 1940, pp. 56/58.) (77/15 Germany.)

The intensity of the sound due to rotation of various profiles over a large speed range was found to vary as the sixth to seventh power of the circumferential speed. Simultaneous experiment on the air friction losses showed that the latter increased as the 3.5th power of the speed. The sound conversion factor at circumferential speeds of 20-50 m. is as low as 10^{-8} or 10^{-9}, but increases to a multiple of 10^{-3} at 250 m./sec.

No satisfactory aerodynamic explanation of these phenomena has been found. A theory embracing all the known facts would be of great value so as to indicate methods of sound reduction.

New Researches on Profile Characteristics. (F. Riegels, Luftwissen, Vol. 6, No. 12, Dec., 1939, pp. 299-304.) (77/16 Germany.)

The author refers briefly to the theoretical methods now available for calculating the pressure distribution on a given profile. Strict accuracy is only possible in the case of certain families of profiles (Joukowsky, Kármán-Trefftz, Betz-Keune, Piercy), but thanks to the work of Theodorsen and others, the pressure distribution can be calculated with sufficient approximation for any arbitrary aerofoil.

The converse problem, *i.e.*, the construction of a profile having a given pressure distribution has also been attacked. If the new pressure distribution only differs slightly from that of a known profile, the method is relatively simple (Betz, L.F.F., Vol. 11, No. 1, 1934). The general case is complicated by the fact that the given pressure distribution must satisfy certain conditions in order to produce satisfactory profiles. In addition the determination of the imaginary part of the logarithmic derivation of the image function is not very accurate, especially in the neighbourhood of the stagnation point.

These difficulties have lately been overcome by Mangler, using a graphical evaluation of the Poisson Integral (1938 Yearbook of German Aeronautical Research, Vol. 1, p. 46). In the remainder of the article, the author deals with experimental work on maximum lift and profile resistance. Measurements of this type are sensitive to the amount of turbulence in the wind tunnel as well as to support interference effects. On applying suitable corrections for these factors, satisfactory agreement is obtained between the results of various laboratories.

Although the past ten years have already yielded promising results, the author is of the opinion that real progress in profile design, including boundary layer control, is only about to begin.

Principles, Practice and Progress of Noise Reduction in Aeroplanes. (A. London, N.A.C.A. Technical Note No. 748, Jan., 1940, pp. 1-66.) (77/17 U.S.A.)

Progress in noise reduction in aircraft has only been made possible by a full application of the principles of acoustics. The whole problem is reviewed:—Nature of sound and hearing; physical and physiological scales of noise measurement; sources of noise in aircraft, *e.g.*, propeller, engine and exhaust, aerodynamic and ventilation.

In order to obtain the maximum sound reduction in an aircraft cabin, the walls must be bad conductors of sound and the internal surface must have a high absorption coefficient. The same result can be obtained by emphasising either one or other of these two factors, the question of weight being of paramount importance. Both transmission and absorption are affected by frequency and to obtain a uniform reduction over a large range of frequency is difficult.

In the case of absorption, a satisfactory compromise can be effected by mounting a porous material on a membrane permitting vibration. Thus asbestos sprayed on metal lath and surface painted is satisfactory over the whole frequency range

from 128 to 4,096 vibrations/sec., the high frequency end being dealt with by the porous material, whilst the panel vibrations absorb the low frequency sound. As regards transmission of sound, the most important determinant of insulation efficiency of a homogeneous panel is its mass. This practically rules out solid structures and composite panels with intermediate air spaces are now generally used. These are designed so that the sound energy in the air space is absorbed and there is no elastic coupling between the solid walls via the air space. Thus the filler (hair felt, balsam wool, etc.) must be loosely distributed, which, under service operation, may cause its disintegration and compacting, to the great detriment of the sound insulation.

Rigorous Performance Prediction without Drudgery. (E. G. Reid, J. Roy. Aer. Soc., Vol. 44, No. 350, Feb., 1940, pp. 176-94.) (77/18 Great Britain.)

The principal departure which characterises the new method is the adaptation of Eiffel's logarithmic propeller chart to the construction of available power curves. The use of " indicated air speed " ($\sigma^{\frac{1}{4}} V$) and the analogous quantity " indicated power " ($\sigma^{\frac{1}{4}}$ h.p.) as co-ordinates causes a single curve to represent the power requirements for level flight at all altitudes. Other simplifications arising from the recognition of certain engine characteristics, utilisation of the unique properties of the Eiffel chart and development of a convenient method of evaluating the excess available power (from logarithmic curves) make it possible to eliminate a large portion of the labour previously required for rigorous performance prediction. The method is not only applicable to, but especially convenient in, the case of the constant speed propeller; moreover, it yields complete level flight and climb characteristics for altitudes below, as well as above, the critical altitudes of supercharged engines.

A Generalised Vortex Theory of the Screw Propeller and its Application. (H. Reissner, N.A.C.A. Tech. Note No. 750, Feb., 1940.) (77/19 U.S.A.)

The vortex theory as presented by the author in earlier papers has been extended to permit the solution of the following problems:—

(1) The investigation of the relation between thrust and torque distribution and energy loss as given by the induction of helical vortex sheets and by the parasite drag;

(2) The checking of the theorem of Betz of the rigidly behaving helical vortex sheet of minimum induced energy loss;

(3) The extension of the theory of the screw propeller of minimum energy loss for the inclusion of parasite drag distribution along the blades.

A simple system of diagrams has been developed to systematise the design of aeroplane propellers for a wide range of practical application. Several typical diagrams are presented to illustrate the method.

Damping Formulas and Experimental Values of Damping in Flutter Models. (R. P. Coleman, N.A.C.A. Tech. Note No. 751, Feb., 1940, 28 pp.) (77/20 U.S.A.)

In connection with an investigation of flutter carried out in the N.A.C.A. 8 ft. high-speed wind tunnel it was found necessary to determine the structural ramping in the models tested. The idea of equivalent viscous damping is reviewed and shown to be related to the structural damping coefficient g introduced in N.A.C.A. Tech. Note No. 685. The theory of normal modes is discussed and a number of methods for separating the motions associated with different modes are described. Equations are obtained for use in evaluating the damping parameters from experimental data. Experimental results of measurements of damping in several flutter models led to the following conclusions:—

1. In determining the damping of structures from the shape of the response curve obtained by applying an alternating load at one point of the structure,

use of the analysis for one degree of freedom is justified when: (*a*) the damping is small; (*b*) the points of applying the force and measuring the amplitudes are appropriate from considerations of disturbing normal modes; (*c*) only amplitudes close to the resonant peak are used to determine the non-dimensional damping parameter, δ.

2. When the normal functions for a structure are known, the damping in the different modes can be separately determined from the measured amplitudes at several points along the structure.

3. The measured values of δ for a homogeneous structure are approximately equal in the different modes of vibration.

Aeroplane Stability and Control from the Designer's Point of View. (O. C. Koppen, J. Aeron. Sci., Vol. 7, No. 4, Feb., 1940, pp. 135-40.) (77/21 U.S.A.)

PRINCIPAL CONCLUSIONS.

(1) From all points of view a large tail-length to wing-span ratio is desirable.

(2) All of the requirements for satisfactory controlled motion indicate the desirability of a large vertical tail. The only conflict is with the requirement for spiral stability of uncontrolled motion, which indicates the need for a small vertical tail.

(3) A minimum of dihedral angle is indicated for all cases except that of uncontrolled spiral motion. Except for the case of aileron controllability the use of a larger dihedral, than the minimum required for the proper direction of the rolling moment due to sideslip, is not as harmful to the controlled motion as is the use of a small vertical tail.

LONGITUDINAL REQUIREMENTS.

In the cases in which the centre of gravity has any effect, it appears to be desirable to meet the minimum requirement of the slope of the pitching moment curve with the centre of gravity as far back on the wing chord as possible. The maximum rearward location of the centre of gravity appears to be limited only by structural and performance considerations.

RESEARCH SUGGESTIONS.

Research in the direction of determining the pilot's control motion relative to the motion of an aeroplane while flying in rough air would be most helpful. In addition, data concerning the average pilot's control application lag as affected by the period of the motion, the control force, and the moment of inertia of the control system, should be determined.

The Application of Television to Wireless Controlled Aircraft. (P. Devaux, La Science et la Vie, Vol. 57, No. 274, April, 1940, pp. 371-376.) (77/22 France.)

Wireless controlled pilot-less aircraft have been in use for some time. A well known British type utilises a short wave receiver responding to six different wave lengths (two for direction, one for climb, one for horizontal flight, one for gliding and one for diving). The aircraft is normally stabilised by means of gyroscopes and the reception of the requisite code message on any one of the control wave lengths, the connecting links between the gyroscope and the servo motors operating the controls are suitably modified so as to bring about the required manœuvre. Several safety devices prevent dangerous flying altitudes. Thus a servo motor under aneroid control pulls the machine automatically out of a dive when approaching the ground. The control of such aircraft is from an emitting station on the ground, the pilot-less machine being under visual observation (relatively small distance). The control could, however, also be carried out from

a second aircraft carrying the necessary transmitter. The utility of a pilot-less aircraft would be enormously increased, if it could be fitted with a television apparatus by means of which an image of the field of view is transmitted to the home station. Two difficulties at once arise: the size and weight of the installation and the poor quality of long distance pictures taken in the open air. The latter defect could possibly be overcome by televising not the actual view but a series of photographs taken in quick succession. Such films can be developed and televised within three seconds of exposure and would have the additional advantage that material sensitive to the infra red could be employed (visibility in fog).

Flight Path and Control during the Longitudinal Motion of an Aircraft. (W. Richter, Ing. Archiv., Vol. 11, No. 1, Feb., 1940, pp. 24-36.) (77/23 Germany.)

The motion of an aircraft in a vertical plane under the action of gravity only is determined by the equations

$$\dot{v} = -g \sin \phi - k_w v^2$$
$$v\dot{\phi} = -g \cos \phi + k_a v^2$$

where

ϕ = inclination of flight path,
$k_a = \frac{1}{2} \gamma C_a (F/G)$,
$k_w = \frac{1}{2} \gamma C_w (F/G)$.

The aerodynamic coefficients C_a and C_w are functions of the incidence α and are obtained from the polar diagram of the aircraft under consideration.

In a previous paper, the author has given a graphical solution of the above equations by employing certain nomographs on the assumption that α is a given function of the time. Knowing v and ϕ, both the trajectory and the necessary elevator operation can be determined. The method has now been generalised by the author so that the problem can be solved for the cases when $v = f(\phi)$, v = constant, ϕ = constant, or when either the flight path or the time variation of the elevator deflection are given. In conclusion, the adaptation of the nomographs to conditions of power flight (propeller thrust) is explained.

Measurement of the Forces Acting on Gliders in Towed Flight. (W. B. Klemperer, N.A.C.A. Tech. Note No. 753, Feb., 1940.) (77/24 U.S.A.)

The magnitude, the direction, and the fluctuations of tow forces exerted upon gliders by towing them aloft behind an automobile were measured under a variety of conditions covering a range from gentle to severe types of operation. For these tests, the glider towing force did not exceed 1.6 of the gross weight of the glider. V-G records obtained during the towed flight period as well as during the subsequent return glide to earth showed accelerations in the range from 3 *g.* to -1 g. The results of preliminary aeroplane tow tests are also presented.

An Investigation of the Prevention of Ice on the Aeroplane Windscreen. (L. A. Rodert, N.A.C.A. Tech. Note No. 754.) (77/25 U.S.A.)

An investigation of three methods for prevention and removal of ice on an aeroplane windscreen was carried out in the 7×3 ice tunnel of the N.A.C.A. Check experiments were carried out in flight. The methods involved:—

(1) Heat from an electric source,
(2) Heat from engine exhaust,
(3) Alcohol dispensing rotary blade wiper.

(1) Two panes of glass $\frac{1}{8}$ in. thick were mounted in a frame and separated by $\frac{1}{4}$ in. gap, which contained the heating wires. To aid the transmission of heat, a liquid dielectric (ethylene glycol) was used. Vision through this arrangement

was satisfactory and the wattage for the prevention of ice formation was of the order of 2 watts per square inch of glass surface.

(2) The air is heated by the engine exhaust and passes through the gap between the two glass panes at a speed of about 50 feet per second. The heat required to prevent ice formation is of the order of 900 B.T.U. per square foot per hour, the air entering the panel at 180°F. and leaving at about 150°F. No mention is made of the means adopted for forcing the hot air to circulate in the manner required.

(3) The rotary wiper covered a circle 10 in. diameter and rotated at 300-600 r.p.m. The alcohol consumption for the prevention of ice was of the order of half-gallon per hour, the minimum power required to operate the wiper being of the order of 100 watts.

The wiper dispensing alcohol has the advantage of dispersing raindrops as well as preventing ice formation and of being easily installed. A disadvantage is that it will not remove pre-formed ice nor deal with frost deposits on the cabin side.

The heat-air panel appears to be the most satisfactory solution. There are no moving parts and it uses exhaust gas energy which normally would be wasted.

A disadvantage of any method using heat alone is the inability to deal with unfrozen water drops on the outer surface.

For this reason a combined wiper and hot air system may ultimately be adopted. The existing practice of making part of the windscreen retractable or removable by the pilot will then become unnecessary.

Some Factors Controlling the Development of Electrical Ignition of Aero Engines. (G. E. Bairsto, J. Roy. Aer. Soc., Vol. 44, No. 350, Feb., 1940, pp. 119-175.) (77/26 Great Britain.)

After calling attention to the very onerous conditions under which the ignition system of an aero engine has to operate, the author deals in turn with the electrical characteristics of the modern magneto and coil. It appears that the latter by itself is cheaper to design and manufacture than the magneto and that the coil ignition system is generally easier to instal. Wireless interference is, however, more difficult to guard against and there appears a greater risk of fire on crash (spark or breaking primary circuit). The reliability of the system also suffers and for these reasons the magneto is still holding its own on aircraft, although it has been almost completely displaced in the modern motor car. The remainder of the paper deals with sparking plugs and ignition cables. Special reference is made to the new insulator made of sintered aluminium oxide and to the use of special metals (Ni and Pt-Ir) to reduce erosion of the electrodes. This latter phenomenon by itself limits the life of high duty plugs to about 100 hours.

According to the author, ignition systems, although already astonishingly reliable, require further development to meet the high temperature conditions which are becoming increasingly common on high duty power plants. Both the cables, windings and bearings will have to be improved before the aims of a longer maintenance free period can be achieved.

Predetermination of Aircraft Engine Cooling Requirements for Specific Flight Conditions. (K. Campbell, J. Aeron. Sci., Vol. 7, No. 4, Feb., 1940, pp. 141-7.) (77/27 U.S.A.)

For the past several years, the engine manufacturer has provided the designer with the equivalent orifice area of the engine baffle passages of his various models, which have been established by flow testing; and to facilitate the designer's calculations, direct reading charts relating to cowl exit gap size to baffle pressure drop and cooling drag for any indicated air speed and altitude have been provided.

Until recently, however, one link in the chain of rational cooling system design

procedure has been missing, namely, a quantitative readily workable correlation of the principal variables influencing engine cooling performance under stabilised conditions. This is required so that the aeroplane designer may select the " suitable " baffle pressure drop which he must provide under his assumed conditions of allowable maximum cylinder temperature, brake horse-power, r.p.m., specific fuel consumption, pressure altitude, and prevailing air temperature. The author provides such a correlation in direct reading chart form, for the aeroplane designer's convenience, and some important relations which become evident from its application to specific assumed conditions are briefly discussed.

Researches on Direct Injection in Internal Combustion Engines. (J. E. Tuscher, Pub. Sci. et Tech., B.S.T., No. 89, 1939, 93 pp.) (77/28 France.)

Information obtained from successive experiments, under strictly comparable conditions, using injection devices permitting variation of both injection time and injection pressure, shows that these two factors have a primary effect on the power developed and on the efficiency of a Diesel engine. Experiments carried out in two engines of different types show that the laws relating injection and combustion are general and are not influenced either by the shape of the combustion chamber or by a more or less strong turbulence in the combustion chamber. Study of retarded cycles, in which combustion takes place entirely during the expansion stroke, has provided a means for reducing the combustion speed and for increasing the concentration of the fuel/air mixture up to saturation, while maintaining a high thermal efficiency. Combination of short injection time and a retarded cycle will produce the greatest specific power from a Diesel engine, at the same time reducing fatigue of its parts. Feed of Diesel engines by injection pumps worked by the compression of the engine can easily achieve the high injection velocities required and permits rigorous control of the charge introduced into each cylinder. Avoidance of mechanical control of the pumps and pressure pipes simplifies the construction of direct-injection engines and improves their reliability in operation.

On the Effective Rigidity of Crankshafts Undergoing Torsional Vibrations. (J. Meyer, L.F.F., Vol. 17, No. 2, 20/2/40, pp. 54-55.) (77/29 Germany.)

Grammel (Ing. Arch., Vol. 4 (1933)) pointed out that a crankshaft may be twisted in two different ways, which he designated as torsions of the first and second kind respectively.

Torsion of the first kind arises if a couple is applied to one journal and balanced by an equivalent couple in another journal. The second kind of torsion arises if a single force is applied to the crankpin of one throw and balanced by a force on the crankpin of the next throw. Both calculation, taking into account bearing play, and experiment on single throws show that for the same applied moment the angular twist is greater in the first than in the second case, *i.e.*, a crank throw is apparently stiffer when the force is applied to the pin. This led Grammel to reject the usual method of determining effective rigidity of a crankshaft by applying a couple to one end whilst the other end is fixed. According to his argument the method must lead to an under-estimation of the natural frequency. Now practical experience has shown that the first two orders of frequencies, at any rate, are given in a satisfactory manner for crankshafts with four or more throws when the rigidity is estimated in the usual manner by applying a couple to one end of the shaft. The discrepancy between Grammel's investigation and practical experience has now been found to be due to secondary torsion effects always present in multi-throw shafts and neglected by Grammel. The usual method of obtaining the rigidity of the shaft can thus be retained and will give satisfactory value except for frequencies of a high order which are usually of no great importance.

New Designs for Piston Ring Grooves. (E. Mickel, Luftwissen, Vol. 6, No. 12, Dec., 1939, pp. 305-308.) (77/30 Germany.)

In recent years it has been appreciated that the life of a highly stressed part depends not only on the material utilised but also on the design. It is now well known that sharp corners or edges should be avoided. Nevertheless, piston ring grooves have retained up to now a rigid rectangular shape with sharp corners. It is true that the projecting bands are generally only subjected to small loads and should therefore stand up to their work in spite of the unfavourable shape. As a matter of fact, fatigue fracture of the bands have been relatively rare up to now. With the modern tendency of utilising shorter pistons, combined with increase in the power output of the engine, it is to be feared that breakages will become more frequent unless steps are taken to remedy the faulty design of the ring groove. The author has designed a special machine by means of which both the ultimate and fatigue strength of the piston band can be tested and the effect of change in ring groove shape investigated. If the corner or neck of the groove has constant curvature, the maximum stress concentration occurs near the point of juncture of the circular corner with the band, and this stress concentration is the smaller, the greater the radius of curvature. A large uniform radius, however, reduces the available ring space. For this reason the author recommends increasing the curvature of the neck beyond the critical point, *i.e.*, making the junction of the band with the back of the ring groove sharper. This entails machining the ring groove with a special tool, ground to two different radii. In this way the ring space is practically unchanged whilst the fatigue strength of the band is the same as that of the groove of uniform radius.

The Ageing of Lubricating Oil for Diesel Engines. (H. L. Matthijsen J. Inst. Petrol., Vol. 26, No. 196, Feb., 1940, pp. 72-89.) (77/31 Great Britain.)

(1) The catalytic effect of all the relevant metals, with which the lubricating oil comes into contact in the Maybach Diesel engine on the ageing at 230°C. of a paraffin base oil A, has been examined in the oxidation instrument designed by A. Mollinger (centrifugal oil spray).

All the ferrous metals stimulate ageing more or less.

The non-ferrous metals have no catalytic effect, or a negative one.

(2) From investigations into the effect of the addition of copper as very fine turnings to a paraffin base oil (A) and to a naphthene base oil (B) during ageing progressively from 100°C. to 230°C., it appears that the catalytic effect of copper is very different in the case of the two lubricating oils.

With the paraffin base oil the catalytic effect up to 180°C. is clearly but weakly positive, whereas above 180°C. copper strongly represses the ageing.

There is only a slight catalytic effect over the whole range of temperature with the naphthene base oil.

The Investigation of Rapidly Changing Mechanical Stresses with the Cathode Ray Oscillograph. (S. L. de Bruin, Philips Technical Review, Jan., 1940, pp. 26-8.) (77/32 Great Britain.)

The cathode ray oscillograph has been adapted to measuring extremely small changes in shape in mechanical structures, and these are assumed proportional to the stresses. The deformations are transmitted to an electrical resistance of which one end is fixed to the specimen. The electrical resistance is a piece of flexible insulating material upon which a line is drawn with a suspension of powdered charcoal. The terminal contacts are of silver, and for small vibrations the resistance varies directly with the change in length. A potential varying with the resistance is transmitted to the plates of the oscillograph. The article discusses the sensitivity of the apparatus, its calibration for absolute measurement

and the limits of the deformation for linear variation of the resistance. (Abstract supplied by Metropolitan Vickers Research Department.)

Spring Joints in the Construction of Measuring Instruments. (H. Stabe, Z.V.D.I., Vol. 83, No. 45, 11/11/39, pp. 1189-96.) (77/33 Germany.)

By comparison with point, spindle and knife edge bearings, wires and bands, which are subjected to bending and torsion by the forces to be measured, offer the advantage of considerably smaller internal friction, and therefore greater sensitivity. The reliability and transportability of such instruments is also important. The disadvantage, that the angular deflection is limited and the spring joints are subjected to directional force can be avoided by balancing the forces to be measured against forces in the springs. Examples are given, and illustrated by sketches, of the use of the spring joints in acoustics (tuning forks, strings), mechanics (spring balances and dynamometers, pendulum and balanced suspensions, torsion balances, balance wheels, membranes, tube corrugated tube and leaf springs, etc.), and in electro-technology (band suspension of galvanometer coils, vibration galvanometers, oscillographs, electrometers with metallised quartz fibres, electro-magnetic measuring instruments with spiral spring suspension). Brief reference is made to the properties required of the materials of the springs, calculation of the latter (effect of shape and of cross section), their mounting and damping.

Measurement of the Thickness of Non-Magnetic Layers. (W. Redepenning, Z.V.D.I., Vol. 83, No. 38, 23/9/39, p. 1071.) (77/34 Germany.)

An instrument has been designed as follows:—A measuring knob, which is pressed firmly on to the layer to be measured, contains a coil through which alternating current passes and an iron core. When this is brought near to a piece of iron the impedance of the coil increases to an extent depending on the proximity of the external iron. Thus, after suitable calibration the impedance of the coil serves as a measure of the distance between the pole shoe of the coil and the surface of the iron part, *i.e.*, as a measure of the thickness of the surface layer. This measurement is made in the usual way by a bridge connection and the thickness read off on an electrical measuring instrument graduated in μ. All parts necessary for the measurement are enclosed in a special casing and separate measuring knobs are provided for use on plain and curved surfaces. By suitable adjustment of the sensitivity of the instrument any thickness of layer can be measured to an accuracy of ± 1-2 per cent.

Measurement of Impact Strains by a Carbon Strip Extensometer. (R. Fanning and W. V. Bassett, J. App. Mech., Vol. 7, No. 1, March, 1940, pp. A24-8.) (77/35 U.S.A.)

A method of experimentally ascertaining the actual stress time curve in a mechanical part subjected to an impact blow is described. The apparatus consists of a resistance strain gauge in conjunction with a high speed recording oscillograph, the combination being sufficiently rapid in response to record strain variations occurring within a few micro seconds. Consequently, the strain during impact are recorded with sufficient accuracy for detailed analysis.

Longitudinal strain waves in long bars striking end to end have been subjected to theoretical analysis and have served as a subject for testing of the apparatus. The theory is reviewed in this paper, and computed results based thereon are compared with experimental data. The agreement is shown to be satisfactory, the form being as predicted and the magnitude within a few per cent. of the computed value.

The strain waves and refections occurring in this simple case are surprisingly complex. An investigation of other impact problems by this method such as the

correlation of standard impact tests of materials, might well yield information of considerable value.

The Polishing, Plating and Anodising of the Aluminium Light Alloys. (E. E. Halls, Metallurgia, Feb., 1940, pp. 123-6.) (77/36 Great Britain.)

A description is given of the physical and chemical properties of aluminium and its light alloys, in so far as these affect the general machining and electro-plating of these metals. The final stages of polishing and the use of lacquers are dealt with in detail. Regarding electro-plating, the importance of each operation is explained, and how a sound surface may be obtained which shall give some protection against mechanical maltreatment and corrosion. The review given of anodising extends over pre-cleaning, the choice of suitable electrolytes for different alloys, impurities, pigmenting and the nature of the final film, with a recommendation as to the best selection of these actions for resistance to corrosion. (Abstract supplied by Metropolitan Vickers Research Department.)

Modern Precision Grinding Methods. (R. Brule, Airc. Eng., Feb., 1940, pp. 49-55; translated from Rev. Techn. Hispano Suiza, No. 5, July, 1939.) (77/37 Great Britain.)

For production of components requiring extreme precision in manufacture, grinding wheels are replacing other tools. The nature of the agglomerant, the abrasive, shape of the workpiece and speed of revolution are considered in turn. Particular attention is paid to methods of supporting the work piece for various grinding cuts, including the case of shaped grinders. Details of thread cutting by these tools are given, together with a method by which the accuracy may be checked while the operation is in progress.

The application of grinding to the elastic watertight joint of the cylinders of Hispano-Suiza liquid-cooled engines is described. (Abstract supplied by Metropolitan Vickers Research Department.)

Elastic Theory Involving Finite Displacements (Part II). R. Kappus, Z.A.M.M., Vol. 19, No. 6, Dec., 1939, pp. 344-361.) (77/38 Germany.)

The general theory developed in Part I is applied to problems of stability of rods, plates and shells.

The special case of the buckling of a tube under torsion is treated by the energetic criterium, and a physical interpretation is given of some of the terms in the resulting differential equations, which throws a light on the problem of resistance to buckling.

Speaking generally, it appears that small terms involving the moment balance at the element must be retained, but that those depending on complete isotropy of the material may be neglected when evaluating the equations.

The elimination of terms before the final stages of the investigation is, however, always dangerous since, although the terms may appear to be negligibly small compared with others which are retained, these latter terms may finally cancel out and the correct answer will thus depend on the very terms which had been neglected.

Heat Treatment of Steel by High Frequency Currents. (G. Babat and M. Losinsky, J. Inst. Elec. Engs., Vol. 86, No. 518, Feb., 1940, pp. 161-8.) (77/39 Great Britain.)

There has recently been a great increase in the use of high frequency currents for heat treatment of metals, in such processes as surface hardening, cementation and alloying, welding, hot machining, and zonal tempering. The paper deals chiefly with surface hardening.

After giving an account of the advantages of the process and an estimate of the power requirements, the authors deal with the design of the heating coil in relation to the shape of the specimen, and describe a " model " method whereby the distribution of the electro-magnetic field in the system may be investigated.

Curves are plotted from the authors' experimental results to show the distribution of temperature and current density over the specimen, and the variation of the power absorbed, during the heating period.

The effect of frequency upon the depth of penetration of eddy currents in steel is examined, and consideration is given to the relation between the depth of penetration and the shape of the surface being treated.

Results obtained from the application of the high frequency method to the hardening of tools and gears are discussed.

On the Natural Frequencies of Vibrating Systems. (R. V. Southwell, Proc. Roy. Soc., Vol. 174, No. 959, 8/3/40, pp. 433-457.) (77/40 Great Britain.)

On the basis of a theorem due to Lord Rayleigh and relating to the effect on the natural frequencies of an added mass, methods are developed whereby lower limits can be imposed upon the frequencies of a specified system. Since upper limits can be imposed on the basis of " Rayleigh's principle," information so obtained is for practical purposes of equal value with an exact solution.

The methods can be applied as an extension of the " relaxation " technique, and it is then that their value is revealed most clearly. In this paper attention is confined to continuous systems governed by differential equations, and for these a method is developed whereby specially close estimates of the fundamental frequency can be made if desired.

The concluding section of the paper is concerned with the resolution of a paradox presented by Lord Rayleigh's theorem regarding the effect of a constraint.

As is well known, the natural transverse frequencies of a uniform bar with both ends completely free are higher than if the bar is simply supported. The effect of constraint is thus to lower the frequency in this case in apparent contradiction to Rayleigh's second theorem. Closer investigation of this particular case shows, however, that the relations imposed by momentum conditions in the case of the free bar have the same effect as the relations imposed by clamps prohibiting terminal slopes. The degrees of freedom are thus not reduced and Rayleigh's second theorem does not apply.

An Investigation of Sheet Stiffener Panels Subjected to Compression Loads with Particular Reference to Torsionally Weak Stiffeners. (L. G. Dunn, N.A.C.A. Tech. Note No. 752, Feb., 1940, 39 pp.) (77/41 U.S.A.)

PART I.—Methods are developed for calculating :—

(*a*) The buckling stress of a plate in which the edges parallel to the applied end load are elastically supported and the other two sides are simply supported. The elastic edge support corresponds to the restraining moments induced by the stiffener on the buckling of the sheet.

(*b*) The maximum wave amplitude of the buckled sheet as a function of the stiffener stress and the buckling stress of the sheet. Preliminary work done on theoretical calculation of the stiffener stresses is given in Appendix A.

PART II.—Experimental results are given for tests on 183 panel specimens of 24 ST aluminium alloy of three different thicknesses, stiffened by bulb angles of twelve different shapes, spaced at 4 and 5 inches. Bulb angles from 3 to 27½ inches long were tested as pin-end columns. The experimental data are presented as stress-strain and column curves and in tabular form and compared with theoretical results.

The scope of the tests was insufficient to formulate general design criteria, but the results are presented as a guide for design and an indication of the type of theoretical and experimental work needed.

Effect of Pressing Conditions and Composition on the Properties of Laminated Synthetic-Resin Pressed Plastics. (W. Kuch, Z.V.D.I., Vol. 83, No. 52, 30/12/39, pp. 1309-16.) (77/42 Germany.)

The optimum pressing conditions for production of high grade laminated materials with a binder of phenolformaldehyde resin have been determined. With wood as filler the optimum resin content is about 10 per cent. (referred to the weight of the final material); with cellulose strips it is 26-33 per cent., and with strips of fabric 33-38 per cent. In the case of synthetic resin compressed wood use of pressures higher than 200 kg./cm.^{2} causes destruction of the structure. Production of cellulose and fabric-filled materials of small deformability necessitates use of highest possible compression pressures. Urea resins show advantages as binders for compressed wood. Laminated materials prepared with polyvinyl chloride have low strength and high sensitivity towards moisture. The large deformability of fabric-filled materials can be reduced by hardening the fabric under tension or by pre-treatment. By using a special fabric in this way it is possible to prepare a compressed material for which the strength value, referred to weight, is equal to that of steel. By simultaneous use of several fillers (wood, cellulose, and strips of fabric) materials with improved properties may be prepared. The mechanical properties of these materials may be suitably judged on the basis of micro-photographs of their structure.

Corrugated Panels Under Combined Compression and Shear Load. (P. A. Sanderson and J. R. Fischel, J. Aeron. Sci., Vol. 7, No. 4, Feb., 1940, pp. 148-153.) (77/43 U.S.A.)

An investigation was conducted on a semi-monocoque box beam to determine the combined stress interaction curve for a corrugation skin type of construction under combined compression and shear load. The investigation included the determination of initial buckling stresses and a comparison of measured stresses with computed stresses on the box beam.

The interaction curve presented is most closely represented by the expression $R_c + R_s^{1.7} = 1$ where R is the appropriate stress ratio. Curves of effective width of skin versus corrugation stress, initial buckling stresses for several skin thicknesses, as well as the combined stress interaction curve are included.

It is probable that the addition of shear stresses to compression stresses in structures of this type lowers the effective width of skin acting with the stiffeners, but no proof of this is available. However, many investigators have noted that a very small amount of shear load changes the buckles in the skin from pure compression waves to prevailing buckles of the shear (diagonal tension) type, and the observations made during these tests agree. At any rate, shear stresses do lower the initial buckling stresses, but quantitative data are not available.

Contribution to the Study of Dissolution Potentials. (N. Goldowski, Pub. Sci. et Tech., No. 158, 1939, 102 pp.) (77/44 France.)

Corrosion phenomena depend not only on the metal in question, but also on the attacking medium, and corrosion of a metal can thus be studied only in presence of an absolutely defined medium. The metal dissolves as positive ions, and this dissolution of electric charges creates a difference in potential between the solid surface and the liquid bath, and the corresponding electrical field then brings about equilibrium in the diffusion of the ions; the equilibrium potential difference must thus have a definite value if the constitution of the solid surface and that of the bath are perfectly definite and if capable of measurement, this can be used to characterise the solubility of the metal in the bath considered. But it is only possible to measure the total difference in potential between the electrode studied and a reference electrode in contact with the same electrolyte. This quantity is defined as the dissolution potential, and it has been measured, using a normal calomel electrode as the reference electrode. It has been found

to depend on the surface layer of the metal, the conditions of formation of which have been studied. Some examples of variation in potential, disclosed by the coloriscopic method, led to an experimental study which enabled a relationship to be set up between the curves for potential as a function of time and susceptibility to corrosion of certain light alloys. The report concludes with a study of applications of the method, in particular a study of the variation in potential for steel with temperature of heat treatment.

Effect of Plastic Deformation on the Age Hardening of Duralumin. (R. W. Lindsay and J. T. Norton, Trans. Amer. Inst. Min. Metall. Eng., Vol. 133, 1939, pp. 111-9.) (77/45 U.S.A.)

The behaviour of commercial aluminium. (1) Aged in the normal way; (2) aged after cold-working; and (3) cold-worked after normal ageing, was compared on the basis of measurements of hardness, electrical conductivity and X-ray investigations. The samples were heat treated for one hour at 515° and quenched in water. Ageing took place in constant temperature baths at 25, 100, 190 and 300° (duration up to one week). After definite time intervals the samples were taken from the baths, investigated at 25°, and then given further ageing treatment in the baths. Mechanical deformation was obtained by taking original test bars of $\frac{1}{2}$ in. diameter, cutting down to various diameters and then drawing with a draw plate to the same final diameter. The experimental results, in particular the hardness curves, show that the normal process of ageing takes place in three overlapping stages. At 25° a lattice disturbance occurs (increase in hardness and resistance). No change is observed in the position or breadth of the X-ray lines. The second stage begins at 100°—another increase in hardness, but slight decrease in electrical resistance. The third stage, clearly noticeable at 190° is characterised by general structural change (increase in hardness, with decreasing electrical resistance and increasing lattice parameter). At 300° the process takes place so quickly that the first and second stages can no longer be clearly observed. A lattice disturbance, similar to that of the first stage of ageing, can be obtained by mechanical deformation, but this mechanical disturbance is not identical with the spontaneous lattice disturbance due to ageing; mechanical deformation causes broadening of the X-ray lines. The general structural change takes place in the deformed samples at the same temperatures and in the same manner as in the undeformed samples. Deformation of age-hardened samples causes simple mechanical disturbance of the lattice.

The Behaviour of Thin-Walled Tubes Under Internal Pressure. (R. Moufang, Z.A.M.M., Vol. 20, No. 1, Feb., 1940, pp. 24-37.) (77/46 Germany.)

The author investigates the stress and deformation of a thin-walled circular tube under hydrostatic pressure on the assumption that both the ends and the external surface of the tube have no forces acting on them. It is further assumed that the plastic deformation is independent of time, and that, therefore, the equations of Mises as well as the strain-hardening law of Schmidt can be applied, the volume remaining constant.

In the case of linear strain-hardening, the stresses and deformations are expressed explicitly. In this case the stresses (but not the deformations) are found to be independent of the strain-hardening to a first approximation.

Strength Properties of Light Metal Screws. (F. Bollenrath, H. Cornelius and W. Siedenburg, Z.V.D.I., Vol. 83, No. 44, 4/11/39, pp. 1169-73.) (77/47 Germany.)

Light metal screws, which give considerable weight economy by comparison with steel screws, also assist in reducing corrosion and thermal stresses when used in assembling light metal parts. So far they have hardly been used at all, since insufficient data has been available regarding their properties. A compara-

tive investigation has therefore been made of the strength properties of light metal and steel screws under static and alternating stress and of their behaviour on tightening and loosening. The light metal screws, of ordinary commercial sizes, were made from a ductile alloy of the Al-Cu-Mg class and from an alloy of the same class with addition of lead, comparison being made with unalloyed steel screws of equal yield ratio. The strength tests comprised determination of tensile strength, fatigue bending strength and fatigue tension strength (no load reversal), full data for which are given. Results showed that chromium plating and electrolytic oxidation are not advisable, but that light metal screws are practically equivalent to the corresponding steel screws. For fatigue stressing, however, a lower initial stress should be chosen.

Smooth Skin Riveting in German Aircraft Construction. (W. Pleines, Z.V.D.I., Vol. 83, No. 37, 16/9/39, pp. 1037-1041; No. 38, 23/9/39, pp. 1057-1060.) (77/48 Germany.)

The importance of a smooth skin in modern high speed aircraft necessitates special attention being paid to the riveting. A number of N.A.C.A. and British reports on the effect of rivet heads on minimum profile resistance of the wing as well as their effect on the water resistance of flat plates are reviewed by the author.

For this reason flush rivets have been employed by German aircraft constructors for some time for the whole of the wing surface and for at least the front one-third of the fuselage.

An additional reason for such rivets is the recently discovered fact that the icing up of wings is greatly facilitated by the presence of protuberances such as rivet heads.

Flush riveting can be either of the normal countersunk type in which the rivet head fits, the plates remaining flat, or a certain amount of deformation of the material is produced in the neighbourhood of the rivet shaft during the process of insertion so as to make room for the rivet head, when the rivet is hammered. The latter process is used in Germany as it is more suitable for thin skins, the countersinking of which by drilling would be difficult. The rivet is generally introduced from the outside, as the reverse procedure requires the use of special mushroom rivets and more skill on the part of the operator. The tools are generally pneumatic and operate on the so-called indirect principle, *i.e.*, the blows act on the rivet head whilst the actual closing up of the shaft is due to the inertia mass held by hand. In order to prevent injury to the material, especially in the case of anodised sheets, it is customary to surround the die with a cushion of plastic material such as aluminium.

A Theoretical Investigation of Plastic Torsion in an I-beam. (D. G. Christopherson, J. App. Mech., Vol. 7, No. 1, March, 1940, pp. A1-4.) (77/49 U.S.A.)

The distribution of stress in an I-beam in torsion is investigated by a method of successive approximation, and the regions of initial yielding are determined for several values of the angle of twist. Formulas are given for elaborating the methods of Southwell (1) and of Shortley and Weller (2) in order to facilitate this determination.

The value of the stress concentration factor in the fillets is found to agree well with results obtained by soap film tests, and regions of plastic flow approximate closely to those observed by McGregor and Hrones (3) by the use of the etching method.

Stress Concentration Factors Around a Central Circular Hole in a Plate Loaded Through Pin in the Hole. (M. M. Frocht and H. N. Hill, J. App. Mech., Vol. 7, No. 1, March, 1940, pp. A5-9.) (77/50 U.S.A.)

This paper deals with factors of stress concentrations in plates of finite width with central circular holes loaded through pins or rivets. Two sets of results are

presented, one from oversize aluminium specimens in which the stresses were determined from strain-gauge measurements, the other, from photo-elastic tests with small bakelite models. The two investigations were conceived and executed independently. The tests involving the use of strain gauges were made at aluminium research laboratories and the photo-elastic tests were made at the Photo-elastic Laboratory of the Carnegie Institute of Technology.

While most of the tests involved plates loaded through a single pin in a hole on the longitudinal centre line of the plate, several tests were made on plates loaded through two pins symmetrically situated about the centre line of the plate. Numerical values for the stress concentration factor k are given for ratios of hole diameter to width of plate ($2\,r/D$) ranging from 0.086 to 0.76.

The Distribution of Load on the Threads of Screws. (J. N. Goodier, J. App. Mech., Vol. 7, No. 1, March, 1940, pp. A10-16.) (77/51 U.S.A.)

The distribution of load on the threads of screws and the types of deformation affecting it have been investigated by means of extensometer measurements made on the outside of the nut. The types of deformation characteristic of concentrations of load on different parts of the thread were found by using a bolt carrying only a single turn of thread. At low loads the deformations of nuts with complete bolts closely resemble the effects of the artificial concentration of load on the base part of the thread, whereas there are marked contrasts with the effects of loads concentrated at the middle or at the free end. At higher loads a more uniform distribution is indicated. Similar conclusions follow from the application of an approximate method for deducing the distribution from the deformation measurements.

It is shown that the distribution is governed by (*a*) stretch and compression in bolt and nut, respectively, which are primarily responsible for concentration at the base; and (*b*) by bending of the thread, circumferential stretch (at the base), and contraction (near the free end) of the nut wall, which have comparable effects in reducing the concentration.

Deformation and Fatigue of Metallic Materials as Detected by X-Rays. (F. Regler, Forschungsarb. Metallkunde Rontgenmetallog., No. 26, 1939, 98 pp.) (77/52 Germany.)

Deformation of metals causes both peripheral and radial broadening of X-ray diffraction spots. A number of examples of peripheral broadening brought about by cold deformation and fatigue are shown. With moderate reductions the spots tend to merge to form lines and with increasing reduction the well known fibre structures result. The significance of radial broadening is discussed. Measurements of this indicate that radial line width tends to a maximum which characterises the material; this is termed the " fracture line width." This was 6.30 mm. for pure iron and as high as 7.80 for some alloy steels. On fractured specimens the line width rises slowly to a maximum at the point of fracture. On notched specimens the width increases abruptly at the notch. The maximum of the line width on materials subjected to fatigue but not fracture was found to indicate where fracture would ultimately occur. Measurement of the line width in and near welds indicated positions of stress concentration. Several practical applications of radial broadening of X-ray lines are given and detailed directions for X-ray study of fatigue damage are given. (From Chem. Absts., Vol. 34, No. 6, 1940, p. 1598.)

Forging and Stamping of Aeroplane Propeller Blades from Magnesium Alloys of High Strength. (S. M. Voronov and L. Y. Shpolyanski, Avia Promyshlennost, No. 2, 1939, pp. 24-33.) (77/53 U.S.S.R.)

Magnesium alloys containing 4.5-5 per cent. Al, 0.5-0.6 per cent. Zn and 0.3-0.5 per cent. Mn are much less easily forged than alloys of the type Dow F. The maximum deformation occurring during forging should not be greater than

20-25 per cent. to prevent destruction of the material. The alloy has a narrower temperature interval of forging than alloys of the Dow type containing 4-4.5 per cent. Al. The recommended temperature interval 330-350°. The stamped blades of the Al-Zn-Mn alloy should be heat treated by either of the following methods:—(i) Heating at 350-400° for 6-12 hours followed by air cooling; (ii) heating at 420° for 2 hours followed by 12 hours ageing at 200°.

Protective Enamel Finishes for Magnesium Base Alloys. (E. E. Halls, Products Finishing, Vol. 4, No. 3, 1939, pp. 42-6.) (77/54 U.S.A.)

Since magnesium is strongly electro-positive, the enamelling and painting of its alloys is difficult and it is necessary to convert the surface into an inert layer by any one of a number of aqueous pre-treatment processes, mostly having a chromate base. Tables are given showing the behaviour of enamelled magnesium alloys in a salt spray atmosphere, in hot and cold humid atmospheres and under weathering; data are given for the alloy composition and the characteristics of the primers and enamels used on the test specimens. All types of exposure tests show the advantages of using chromate pre-treatment or a special primer, in particular of a chromate primer with or without chromate pre-treatment. Appreciable advantages can be obtained by using an ordinary red oxide variety of primer, but the benefit is not so great as with the zinc chromate type. The data given show that satisfactory results are obtainable without departing from normal commercial practice. The groundwork is provided by an aqueous chromate pre-treatment and a synthetic zinc chromate primer. The usual commercial finishing coats are then applied.

A Buna Fabric Gasket Free from Asbestos. (K. Diehl, Autom. Tech. Zeit., Vol. 43, No. 5, 10/3/40, pp. 123-4.) (77/55 Germany.)

Use of asbestos containing materials for packing is not now desirable in Germany from the point of view of the raw material situation. A new type of gasket has therefore been developed from synthetic rubber (Buna). The latter differs from natural rubber in not being liable to soften at high temperature; on the contrary, it is much more inclined to stiffen (due to cyclisation) and therefore can withstand higher temperatures, in the capacity of a packing material, than can natural rubber. The main problem has been to find a suitable filler. The new gaskets have steel inserts, preferably consisting of two layers of metal wire fabric, vulcanised into the synthetic rubber. The meshes of these wire fabrics do not run parallel, but one is displaced by 45°, thereby ensuring high strength. Owing to the elastic nature of the rubber surface the new gaskets fit very closely; they are practically unaffected by heat, not liable to formation of a graphite layer, stable towards hot water, hot oil, glycol, petrol, leaded petrol, various acids, alkalis and organic solvents.

Reciprocity Failure of Photographic Materials at Short Exposure Times. (W. F. Berg, Proc. Roy. Soc., Vol. 174, No. 959, 8/3/40, pp. 559-68.) (77/56 Great Britain.)

Experiments at very high intensities and at various temperatures show that for sufficiently short exposures reciprocity failure disappears. The bend-over point in the reciprocity failure curve is shown to be connected with the mobility and concentration of the interstitial $Ag+$ ions, and below room temperature varies with temperature as the mobility. These results provide further confirmation that the latent image is formed by the aggregation and neutralisation of silver ions on sensitivity specks.

New High Temperature X-Ray Camera. (E. C. Ellwood, J. Inst. Metals, March, 1940, pp. 87-96.) (77/57 Great Britain.)

The camera is designed to study the constitution of aluminium-zinc alloys at temperatures above 275°C. The X-ray tube used is of the demountable, hot-

cathode, continuously evacuated type with an output of 25 m.a. at 50 kv., using copper radiation. To prevent oxidation, the specimen is sealed in a thin silica container; this is placed in a hole drilled in a steel rod, the rod being adjustable from a rotating head. Heating is carried out entirely by radiation from two similar china clay alumina pots placed mouth to mouth with a 2 mm. gap between, the pots being heated by the electric resistance method using bright-ray wire. The film is held to a detachable film carrier which can be removed without disturbing the position or temperature of the camera. (Abstract supplied by Metropolitan Vickers Research Department.)

Heat Transfer in Vibrating Gases. (R. Sinn, Z.V.D.I., Vol. 83, No. 45, 11/11/39, pp. 1197-9.) (77/58 Germany.)

Measurements of heat transfer in vibrating gases were made by a new method depending on compressing a gas, and giving vibratory motion to the piston during compression. From the measured pressure distribution, it is possible to calculate the quantity of heat given up to the wall during compression. These quantities were compared with the corresponding values for heat transfer to the wall during compression without vibration. Experimental results show that when the vibration amplitude of the gas is sufficiently large the heat transfer may be a multiple of the value for a stationary gas. The results are employed to explain the increased heat transfer and associated decrease in power internal combustion engines during knocking.

Measurement of Stagnation Temperature. (W. Wimmer, Ing. Archiv., Vol. 11, No. 1, Feb., 1940, pp. 1-23.) (77/59 Germany.)

If we attempt to measure the temperature of a flowing gas by introducing a thermometer, the flow is naturally disturbed and the temperature will vary depending on the shape of the instrument. At the stagnation point, the flow is brought to rest and if the compression is carried out without loss, the temperature at this point will exceed the static or undisturbed temperature by a definite amount corresponding to the compression work. Thus if

T_w = static temperature of undisturbed flow at velocity W_o.
T_{st} = stagnation temperature.
$T_w = T_{st} - (A \,.\, W_o^2)/(2gC_p)$.

Since the last term can be calculated, T_w follows from the measured stagnation temperature. Various shapes of thermometers were investigated by the author, the best result being obtained if the thermocouple was placed a small distance ahead of the theoretical stagnation point. Under these conditions fresh hot air is continually brought into contact with the couple and a higher temperature is indicated than at the stagnation point itself where the heat loss is not compensated (zero flow). By employing a sphere, the error in the recorded stagnation temperature is not more than 1-2 per cent. at high flow rates.

The author investigated arrangements of this type of various dimensions and by applying the laws of similarity to the heat balance, a correction for heat loss is obtained which can be applied to any given thermometer.

The Behaviour of a Long Period Physical Pendulum of One Degree of Freedom and Unresponsive to Acceleration when Moving in a Circular Orbit of Small Radius. (E. Schmid, L.F.F., Vol. 17, No. 1, 20/1/40, pp. 32-36.) (77/60 Germany.)

The case of the so-called 84 min. pendulum which does not respond to acceleration has been treated in a previous report by the author (Yearbook of German Aeronautical Research, 1938, Vol. 3, pp. 6-9) (Air Ministry Translation Nos. 905 and 906).

The author points out in the present paper that for a physical pendulum of great effective length, the variation of the force of gravity along the length must be

considered. This not only affects the period, but also the stability of the vertical as a position of equilibrium.

If the axis of rotation of such a pendulum of one degree of freedom is guided to be tangential to a circular orbit, stability is only obtained in the vertical pendulum position if the diameter of the orbit exceeds a certain value, depending on the velocity of translation in the orbit. For smaller values of the radius, there are two positions of equilibrium, neither of which agree with the vertical. If the orbit is sufficiently large or the time of rotation sufficiently long, a second stable vertical position arises, in which finally (with zero orbit velocity) the centre of mass is vertically above the point of support. The two periodic times at zero orbit velocity and small amplitude are 42.2 and 59.7 min. respectively, depending on whether the centre of mass is below or above the point of support.

LIST OF SELECTED TRANSLATIONS.

NOTE.—Applications for the loan of copies of translations mentioned below should be addressed to the Under-Secretary of State (R.T.P.), Air Ministry, Dept. ZA, London, W.C.2, and will be loaned as far as availability of stocks permit. Suggestions concerning new translations will be considered in relation to general interest and facilities available.

Lists of selected translations have appeared in this publication since September, 1938.

TRANSLATION NUMBER AND AUTHOR.	TITLE AND JOURNAL.
983 Kalikman, L. E. ...	*Effect of Profile Form on Friction Drag. Investigation of the Turbulent Boundary Layer in the Region of Breakaway.* (C.A.H.I. (Moscow), Report No. 333, 1937.)
993 Lazzarino, L. ...	*Investigations on Airscrews for High-Speed Aircraft.* (L'Aerotecnica, Vol. 19, No. 7, July, 1939, pp. 760-780.)
995 Vladomiroff, A. N....	*The Approximate Hydrodynamic Calculation of an Underwater Wing of Finite Span.* (C.A.H.I. (Moscow), Report No. 311, 1937.)
1016 Kosberg, S. A. ...	*Lubrication of High Pressure Petrol Injection Pumps.* (Aeron. Eng., U.S.S.R., Vol. 13, No. 2, Feb., 1939, pp. 56-60.)

REVIEWS.

Light and Colour in the Open Air.

M. Minnaert. G. Bell and Sons. 1940. 15/- net.

This is a most interesting book for all lovers of nature. It is the lighter side, as it were, of meteorology and physics, simple observations and explanations of everyday changes in outdoor phenomena and of rare occurrences which, once seen, remain a vivid memory for ever. As the author rightly remarks in his preface, " The importance of outdoor observations for the teaching of physics has not yet been sufficiently realised, . . . they lead us by natural methods to ask a thousand questions."

We see so much and take it so much for granted that many of us remain ignorant all our lives of the most elementary answers. The sunlight fades through the trees and throws a thousand and one spots of light on the ground, all of them elliptical. Why? The reasons for the sharpness of shadows at one point and their blurred outline at another, double shadows, and the astonishing effects of light reflections and refraction are dealt with in the first few chapters. Chapter IV deals with the curvature of light rays in the atmosphere and the mirages which follow. It will interest those who have never seen a mirage to learn how they can see them on any hot sunny day if they wish. Many motorists must have been deceived by the pools of water in the road ahead in the summer—pools which disappear as one approaches them—but one wonders how many have puzzled out the cause of this optical illusion. In this chapter is the explanation of the old legendary green ray from the setting sun and why stars twinkle.

There are so many things of interest in this book that one can only pick out a few here and there to comment upon. In Chapter X the explanation of varying size rainbows, and the theory of rainbows are given, but, what is still more interesting, how to make your own rainbows. Have you ever seen a horizontal rainbow?

For airmen the phrase " visibility five miles " is not only of importance, but conveys a definite idea of visibility. But pilots who come from north of the Tweed may not interpret the following remarks of the author in perhaps the right spirit :—

" In a small town in Scotland the visibility was found to be six or nine times greater when the wind blew from the mountains than when it had passed over a densely populated region."

This is a book one would like every youngster to read who intends to take a scientific or engineering training. It is a book which teaches, simply and clearly, how to observe, how to experiment, and how to draw conclusions. And the apparatus costs nothing and is in the possession of everyone. Nature itself is the material, with the eye and brain of the observer as the instruments.

Metallurgical and Industrial Radiology.

Kenneth S. Low. Pitman and Sons, Ltd., 1940. 7s. 6d. net.

The great advance of the use of X-rays in industry in recent years is symptomatic of the increasing vision of the great manufacturing concerns in making use of every scientific aid to obtain the finest finished product.

In no class of engineering so much as aircraft engineering, is it so necessary to make certain that the final product is as free from flaw as human care can make it. External examination of materials, and the testing of specimens, have

always been carried out with meticulous care, but internal examination has been difficult until the arrival of the X-ray and the new technique of examination which followed its industrial application.

Mr. Low has written not only an extremely informative book, but one which is very readable to those who have no knowledge of the theory of X-rays. Here he shows the unlimited field of investigation which is open to those using this technique, gives an outline of the apparatus and equipment, the technique of obtaining the best results and interpretation of the photographs obtained. The book contains some remarkably beautiful photographs of the examinations of castings and welds. Apparatus capable of dealing with steel plates up to five inches in thickness is now available, and the examination of most welded structures used in aircraft engineering is comparatively simple, but, as the author very rightly points out, X-ray examination is only part of the complete examination.

To all those who are concerned with the safety of aircraft, this book must prove a valuable addition to their bookshelves.

THE ROYAL AERONAUTICAL SOCIETY

WITH WHICH IS INCORPORATED THE INSTITUTION OF AERONAUTICAL ENGINEERS.

MONTHLY NOTICES,

JUNE, 1940.

Emergency Arrangements.

It should be made clear that although the Society has published from time to time in the Journal its emergency address and telephone number (which can be used at any time alternatively with those of the Society), the Society functions, and has functioned from the beginning of the war, from No. 4, Hamilton Place, W.1. It will continue to function from London as far as possible, even though some of the staff may have to be moved, others will continue in London itself. It is obvious that events may make things difficult and cause a certain amount of delay, and members are asked to bear these events in mind.

The emergency address is—

Brook House,
Old School Lane,
Brockham, Surrey.

Telephone: Betchworth 189.

Election of Members.

The following members were recently elected:—

Associate Fellows.—Harold Leslie Cox, Harry Connell Fox (from Student), Wilfrid Samuel Jerome, Herbert Charles MacLeod Stevens.

Associate.—Charles Alastair Wood-Collins.

Graduates.—John Vredenburg Inglesby (from Student), Herbert Edward de Sueur (from Student), David Ronald Newman (from Student), George Selwood, Edward Maurice Ware (from Student).

Students.—Heinz Koppel, Russell Howard Morgan, John Penning, Robert James Ross, Leslie St. Leger, Robert Hastings Shaw, Robert Skinner, Howard Stoddard-Howell, Charles Frank Watkinson.

Companions.—Wilfred Taylor Rogers, Constance Babington Smith.

Library.

The Library will be closed on Saturday afternoons from June 15th for the Summer months. Members may obtain books from the Library through the post on application. The Library will be open as usual from 9.30 to 5 o'clock from Monday to Friday and from 9.30 to 12.30 on Saturdays.

Technical Memoranda.

The President and Council wish specially to acknowledge the great courtesy and help of the National Advisory Committee for Aeronautics in arranging for copies of Technical Memoranda to be supplied to the Library of the Society. These Memoranda, translations of important papers, are an extremely valuable source of information. A list of those received this month is published in the Additions to the Library. They can only be consulted in the Library and are not available for loan.

Royal Academy.

Mr. W. Walker, Associate, who has specialised in the planning of military and civil aerodromes and camouflage, has had two of his works accepted by the Royal Academy.

Acknowledgments.

The President and Council acknowledge gratefully a large number of Journals of the Society (from 1922-1939) from the Past-President, Mr. H. E. Wimperis.

Additions to the Library.

AA.—Aeronautical Research Committee: Reports and Memoranda:—

No. 1849 (revision of 1675). A Graphical Method of Calculating the Performance of an Airscrew. By C. N. H. Lock. 1938. 12/-.

No. 1850. Reports and Memoranda published between 1st Dec., 1936, and 30th June, 1939. 1/3.

No. 1859. General Investigation into the Characteristics of the C.30 Autogiro. P. A. Hufton and Others. 1938. 10/-.

No. 1863. Flight Tests of a Falcon fitted with an Irving Flap. By J. Cohen and Sq. Ldr. H. P. Fraser. 1938. 2/6.

No. 1800. Flight Experiments on Boundary Layer Transition in Relation to Profile Drag. By A. V. Stephens and J. A. G. Haslam. 1938. 7/6.

No. 1847. An Investigation of Ground Effect with a Model of a Mid-Wing Monoplane. By E. Ower, R. Warden and W. S. Brown. 1938. 4/-.

No. 1864. Some Experiments on the Balancing of Wing Brake Flaps. By H. B. Irving and G. A. McMillan. 1939. 3/-.

No. 1865. Wind Tunnel Corrections on Ground Effect. By W. S. Brown. 1939. 4/6.

No. 1866. The Use of a Freely Rotating Windmill to Improve the Flow in a Wind Tunnel. By A. R. Collar. 1939. 1/6.

No. 1867. The Effect of a Gauze on the Velocity Distribution in a Uniform Duct. By A. R. Collar. 1939. 1/6.

No. 1868. Abstracts of Papers published Externally. 1939. 3/-.

No. 1869. The Influence of Wing Taper on the Flutter of Cantilever Wings. By W. J. Duncan and C. L. T. Griffith. 1939. 4/6.

No. 1870. Tests on Two Joukowski Sections in the Compressed Air Tunnel. By D. H. Williams, A. H. Bell, and A. F. Brown. 1939. 2/6.

No. 1871. The Royal Aircraft Establishment Blower Tunnel. By D. W. Bottle. 1939. 1/-.

UU.a.—National Advisory Committee for Aeronautics: Technical Notes:—

No. 747. Propeller Rotation Noise due to Torque and Thrust. By Arthur F. Deeming.

No. 748. Principles, Practice and Progress of Noise Reduction in Airplanes. By Albert London.

No. 749. A New Method of Studying the Flow of the Water Along the Bottom of a Model of a Flying Boat Hull. By Kenneth E. Ward.

No. 750. A Generalised Vortex Theory of the Screw Propeller and its Application. By Hans Reissner.

No. 751. Damping Formulas and Experimental Values of Damping in Flutter Models. By Robert P. Coleman.

No. 752. An Investigation of Sheet-Stiffener Panels subjected to Compression Loads with Particular Reference to Torsionally Weak Stiffeners. By Louis G. Dunn.

No. 753. Measurement of the Forces acting on Gliders in Towed Flight. By W. B. Klemperer.

UU.c.—National Advisory Committee for Aeronautics: Technical Memoranda:—

No. 901. Investigations and Experiments in the Guidonia Supersonic Wind Tunnel. By Antonio Ferri.

No. 902. Design of Centrifugal Impeller Blades. By A. Betz and I. Flügge-Lotz. (From Ingenieur-Archiv., Vol. 9, Dec., 1938.)

No. 903. Effect of Transition in Cross-Sectional Shape on the Development of the Velocity and Pressure Distribution of Turbulent Flow in Pipes. (VDI-Forschungsheft 389, March-April, 1938.) By Edwin Mayer.

No. 904. Stability of Rectangular Plates with Longitudinal or Transverse Stiffeners Under Uniform Compression. By R. Barbre. (Ingenieur-Archiv, Vol. 8, No. 2, 1937.)

No. 905. Temperature Indicating Paints. By F. Penzig. (Z.V.D.I., Vol. 83, No. 3, Jan., 1939.)

No. 906. Forces and Moments on a Yawed Airfoil. By Sighard Hoerner. (Luftfahrtforschung, April, 1939.)

No. 907. Dynamic Stability of a Helicopter with Hinged Rotor Blades. By K. Hohenemser. (Ingenieur-Archiv, Dec., 1938.)

No. 908. Two-Stroke Cycle Engines with Unsymmetrical Control Diagram (Supercharged Engines). (A.T.Z., August, 1938.) By J. Zeman.

No. 909. The Theory of Contra-Vanes Applied to the Propeller. By Albert Betz. (Ingenieur-Archiv, December, 1938.)

No. 910. Measurements on a Low-Wing Model in the Rotating Jet and Comparison with Flight Measurements. By W. Bader. (Luftfahrtforschung, Feb., 1939.)

No. 911. Knocking in the Otto Cycle Engine. By H. Weinhart. (Luftfahrtforschung, February, 1939.)

No. 912. Increase of the Specific Load under Tension, Compression and Buckling of Welded Steel Tubes in Airplane Construction by Suitable Treatment of Structural Steel and by Proper Design. By J. Müller. (From Luftfahrtforschung, Dec., 1938.)

No. 913. Measurement of the True Dynamic and Static Pressures in Flight. By Georg Kiel. (Luftfahrtforschung, December, 1938.)

No. 914. Engine Knock and Combustion Chamber Form. By Karl Zinner. (A.T.Z., May, 1939.)

No. 915. Experimental and Analytical Investigation of a Monocoque Wing Model Loaded in Bending. By E. Schapitz, H. Feller and H. Köller. (Luftfahrtforschung, December, 1938.)

No. 916. Activation of Hydrocarbons and the Octane Number. By Marcel Peschard. (Ministère de l'Air, P.S.T., No. 132, 1938.)

No. 917. The Effect of Compressibility on the Pressure Reading of a Prandtl Pitot Tube at Subsonic Flow Velocity. By O. Walchner. (Jahrbuch der Luftfahrtforschung, 1938.)

No. 918. The Enlarged N.A.C.A. Tank and Some of its Work. By Starr Truscott. (Jahrbuch der Luftfahrtforschung, Supplement, 1938.)

No. 919. Report on Ice Formation in Aircraft. French Committee for Study of Ice Formation. (Ministère de l'Air, B.Sc.T., No. 85, May, 1938.)

No. 920. The Effect of the Slipstream on an Airplane Wing. By A. Franke and F. Weinig. (Luftfahrtforschung, June, 1938.)

No. 921. Contribution to the Aerodynamics of Rotating Wing Aircraft. By G. Sissingh. (Luftfahrtforschung, June, 1938.)

No. 922. The Breda Wind Tunnel. By Mario Pittoni. (Auto-Moto-Avio, March, 1939.)

No. 923. Measurement of the Air Flow Velocity in the Cylinder of an Airplane Engine. By Hermann Wenger. (Luftfahrtforschung, Feb., 1939.)

No. 924. Modern Methods of Fuel testing. By F. Seeber. (Luftfahrtforschung, August, 1939.)

No. 925. Effect of Wing Loading, Aspect Ratio and Span Loading on Flight Performances. By D. Göthert. (Luftfahrtforschung, May, 1939.)

No. 926. D.F.S. Dive Control Brakes for Gliders and Airplanes. By H. Jacobs and A. Wanner. (Luftwissen, July, 1937.)

No. 927. Constant Pressure Blowers. By E. Sörensen. (Z.V.D.I., Aug., 1939.)

No. 928. Knocking in an Internal Combustion Engine. By A. Sokolik and A. Voinov. (Tech. Physics of U.S.S.R., Vol. 3, No. 9, 1936.)

No. 929. Aerodynamics of Rotating-Wing Aircraft with Blade Pitch Control. By A. Pflüger. (Luftfahrtforschung, July, 1939.)

No. 930. Experimental Contribution to the Study of Combustion in Compression-Ignition Engines. By R. Duchêne. (Ministère de l'Air, P.S.T. No. 149, 1939.)

No. 931. Testing of High Octane Fuels in the Single-Cylinder Airplane Engine. By Fritz Seeber. (Luftfahrtforschung, January, 1939.)

No. 932. Theoretical and Experimental Investigations of the Drag of Installed Aircraft Radiators. By W. Barth. (5th International Congress for Applied Mechanics, Cambridge, Mass., 1938.)

No. 933. The Strength of Shell and Tubular Spar Wings. By H. Ebner. (Luftfahrtforschung, April, 1937.)

No. 934. Application of the Methods of Gas Dynamics to Water Flows with Free Surface. Part I: Flows with no Energy Dissipation. By Ernst Preiswerk. (Institut der Aerodynamik, Technische Hochschule, Zürich.)

No. 935. Ditto. Part II: Flows with Momentum Discontinuities (Hydraulic Jumps).

No. 936. Measurement of Knock Characteristics in Spark Ignition Engines. By R. Schutz. (A.T.Z., Vol. 42, No. 13, July, 1939.)

NOTE.—These Technical Memoranda may *not* be borrowed from the Library. We have, however, loan copies of Nos. 873-900. (For titles, see R.Ae.S. Journal, December, 1939.)

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J. LAURENCE PRITCHARD, *Secretary and Editor.*

COUNTER-ROTATING PROPELLERS.*†

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Paper presented at the Aerodynamics Session II, Eighth Annual Meeting of the Institute of the Aeronautical Sciences, Inc., New York City, New York, January 26, 1940.

ABSTRACT.

This paper is concerned mainly with that application of counter-rotating propellers referred to as " dual-rotation " propellers. This term is here defined to apply to a pair of oppositely-rotating propellers operating in close tandem, mounted on concentric shafts. Only the application to aeroplanes is discussed herein, for the application of these principles to helicopter design is considered another subject.

This paper presents a summary of the development and background of dual-rotation propellers and the benefits that can be derived from their use. Complete references are furnished for designers, no attempt being made to reproduce the somewhat involved theory and lengthy reference data.

A short history of the three applications of counter-rotating propellers is presented. The applications include multi-motored aeroplanes with oppositely-rotating propellers, aeroplanes with engines mounted in tandem (back to back) so that the propellers revolve in opposite directions, but primarily, aeroplanes with dual-rotation propeller installations.

Most present-day aeroplanes with maximum velocities of 350 m.p.h. and over have single-rotation propellers. At this velocity the single propeller is operating past the peak of its efficiency. The loss in efficiency increases rapidly with increasing forward velocity. Dual-rotation propellers offer an excellent means of maintaining peak propeller efficiencies up to aeroplane velocities of about 450 m.p.h. by absorbing the rotational energy losses in the propeller slipstream. At velocities above 450 m.p.h. up to the limiting velocity there will be only a small reduction from the peak in dual-rotation propeller efficiencies.

Sustained level flight aeroplane velocities appear to be limited to about 550 m.p.h. when propellers are used as the means of propulsion. The efficiency of a conventional single-rotation propeller will be so low, however, that this limiting velocity can be approached with such a propeller only at a prohibitive cost in engine horse-power. Any given velocity above 300 m.p.h. can be obtained with less horse-power if dual-rotation propellers are used to replace a single-rotation propeller with the same total number of blades. The percentage gain in performance will increase with increasing forward velocity when dual-rotation propellers are used.

It is possible that single-rotation propellers with more than four blades will never be commonly used. Instead, dual-rotation propellers with a total of four, six or perhaps even eight blades, will be used in the next decade on many high performance aeroplanes, especially those operating at high altitudes. The types of aeroplanes will include small single-seater racers and fighters and high per-

* The views expressed in this report are those of the author and not necessarily those of the War Department.

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formance, long range bombers and transports, particularly those with supercharged cabins.

The discussion brings forth the fact that there are few experimental data available in this country to allow a quantitative engineering evaluation to be made of the worth of dual-rotation propellers. Sufficient substantiated theory exists, however, to permit the general statements made above. An outline of the experimental tests that are required to check the theory is presented.

Following the discussion of tests made by the U.S. Air Corps on a pursuit type aeroplane equipped with a dual-rotation propeller system, comments are made on the relative advantages and disadvantages of dual and single-rotation propellers as they affect aeroplane design. Hub design problems associated with dual-rotation propellers are discussed.

Because of the increasing importance of dual-rotation propellers, additional pertinent references other than those used in this paper are presented in the Appendix.

INTRODUCTION.

The psychological, sport and military factors forcing aeroplane velocities upward each year are outside the scope of this paper. It is recognised that every effort is being made to obtain the highest possible velocity in sustained level flight. The smallest possible aeroplane capable of enclosing a pilot and power plant will undoubtedly be the fastest. It will be necessary to take advantage of every item that will increase the horse-power, lower the drag and maintain or increase the propeller efficiency in order to achieve velocities over 500 m.p.h. (1). The thrust horse-power required to overcome the drag of even the smallest aeroplane will be tremendous. Because of the small size there will be a definite practical limit to the diameter of the propeller. In order to absorb the large horse-power it will be necessary that the propeller has a large number of blades; four, six or even eight, depending on design restrictions. Because of the high forward velocity the blades will be operating at blade angles of 55° to 65° at 0.75 radius. The efficiency of a single-rotation propeller at these high blade angles is well below the peak, mainly because of the high rotational energy losses in the slipstream. A dual-rotation propeller system of the same diameter and with the same total number of blades as the single propeller will absorb these losses with a resulting gain over the single-rotation propeller efficiency. In addition, the considerable adverse torque effect of large horse-power on a small aeroplane will be negated with a worthwhile gain in aerodynamic efficiency.

When replacement of one single-rotation propeller by a dual-rotation system is spoken of in this paper, it is considered that the total number of blades, the diameter, and hence the solidity, are the same. This is the only applicable means of comparison of their relative efficiencies. There are no known aerodynamic, performance or efficiency disadvantages connected with the use of dual-rotation propellers under the conditions above noted. The disadvantages are primarily mechanical ones and will be discussed in detail later.

It is important to note that the application of dual-rotation propellers is not limited to small single-engined aeroplanes where maximum velocity is the main design consideration. High performance bombers and transports designed for optimum ranges can benefit by using these propellers where large engine powers and propeller diameter restrictions make necessary a propeller system of four or more blades. For long range flying the optimum specific fuel consumption is obtained by a reduction in engine r.p.m. while maintaining high manifold pressures in order to reduce mechanical friction and pumping losses to a minimum. The low propeller r.p.m. reduces tip losses but increases the advance ratios and blade angles to such high values that when the peak efficiency for single-rotation propellers is exceeded, dual-rotation propellers should be substituted. Should their application result in any additional weight, they will shortly compensate for

it in increased range through the gasoline saved due to increased propeller efficiency.

Operation at high altitudes where the air is less dense involves higher velocities for a given horse-power. These high velocities at altitude require high blade angles and hence it is expected that dual-rotation propellers will be used on many high performance, pressure-cabin aeroplanes of the future.

Although incidental to the subject of this paper, it is interesting to note that two-speed, or variable speed, reduction gearing can go far to help keep propeller r.p.m. and cruising efficiencies near optimum values, even when conventional single-rotation propellers are used. A minimum of two-speed gearing is desirable to-day and will be required shortly to improve the take-off of high performance bomber and transport type aeroplanes. It is easy to visualise the desirability for variable speed reduction gearing combined with provision for dual-rotation propeller drive. This arrangement approaches the optimum for the propulsive unit of an aeroplane using conventional internal combustion engines and propellers. Variable pitch for propellers is common to-day. Only variable diameter and variable pitch distribution are lacking. The latter two details appear impractical mechanically, and the small increase in propeller efficiency, even if they could be effected, does not appear to be worth the complications involved in their design, construction and operation. Hence the combination of a variable speed reduction gearing with constant speed dual-rotation propeller drive seems to be the practical optimum for propulsive units of high output.

It should be noted here that the important development of two- and variable speed reduction gearing is lagging far behind that of dual-rotation propellers, at least in this country. Watts has presented a very thorough discussion of the benefits that can be obtained by the use of multiple speed reduction gearing (2).

HISTORY.

The history of the development and use of oppositely-rotating, tandem and dual-rotation propellers is very interesting and deserves mention here. Oppositely-rotating propellers are as old as powered heavier-than-air flight itself. Oppositely-rotating propellers were used by the Wright Brothers on their first aeroplane in order to negate propeller torque. This adaption of propellers is coming back into favour again for several reasons.

During the past several years it has been common European practice, particularly in France, to rotate the propellers of multi-engined aircraft in opposite directions, not only to negate the torque, but principally for the appreciable improvement effected in stability, mainly longitudinal. Other advantages are that cooling, exhaust and engine installations are symmetrical, resulting in reduced engineering costs. In addition, single-engined flight performance is the same for either engine, and tail buffeting, vibration and possible flutter, due to unsymmetrical flow over the tail surfaces, are either reduced or totally avoided. The advantages of this arrangement more than compensate for the additional cost and increased number of spare engine and propeller parts required over the more conventional single-rotation arrangement. At least two bi-motored military designs in this country will shortly appear with this arrangement.

Tandem propeller engine arrangements date back as early as the World War. The English had at least three aeroplanes, the Handley-Page, Vickers-Vimy and the C.H. 10, in each of which the engines were mounted back-to-back, giving a spaced tandem, oppositely rotating arrangement. Somewhat similar systems were found in the German Gotha and Siemens-Schuckert. This arrangement is exemplified to-day in the English Short " Singapore " flying boat, the German Dornier DO-18 and DO-26 flying boats, the French Loire-Nieuport flying boat and Farman F-223-1 mail plane, the interesting new Koolhoven fighter and others. The advantages and disadvantages of this system are numerous and are adequately discussed by Watts and Weick in their propeller tests in the chapters on Tandem Propellers (3, 4).

The idea of dual-rotation propellers and a suspicion of the benefits that might be derived from their use dates back at least to 1907, for Lanchester (5) discusses the efficiency of this arrangement and illustrates a patent specification of that date which is for a dual-rotation propeller system. Amazingly, this system provides for equalisation of the torque between the two propellers, provides a clutch, and has the small inner shaft supported in the large outer hub by means of a ball bearing. This general arrangement of support of the inner shaft is identical to that arrived at independently by the U.S. Air Corps for its dual-rotation shaft standards. All this not more than four years after the Wright Brothers' flight in 1903!

There is considerable controversy as to whom credit should be given for the first flight of an aeroplane equipped with this propeller arrangement. The first flight made with a dual-rotation propeller system on a conventional aeroplane, *that has come to the writer's attention*, was that made by Henry Woods, pilot, on June 28, 1931, at Ft. Worth, Texas, in a Travelaire aeroplane with OX-5 engine. This was the development of Messrs. M. M. Egan and D. W. Evans (6).

FIG. 1.

Another interesting but unusual oppositely-rotating, close-tandem propeller system (not dual-rotation) was invented and flown several years ago by C. L. Brown, of Rushville, Missouri (7). In this system the front propeller was attached to the engine crankshaft in the normal manner, but the rear propeller was attached to the engine itself which rotated in the opposite direction, having been converted into a rotary type. The obvious disadvantages of this arrangement are the fuel, oil, ignition and gyroscopic force difficulties inherent in rotary engine installations.

The most notable application of dual-rotation propellers to date was that on the Italian Macchi-Castoldi 72 twin-float racing seaplane, which in 1934 set the world's absolute speed record of 440 m.p.h. This record has only recently been broken by the Germans. That record of 1934, which has stood for so many years, was only possible in that type of aeroplane because of the dual-rotation propellers. The torque otherwise would have forced the opposite float so deeply into the water that take-off probably would have been impossible (8).

Since 1934 two more dual-rotation propeller installations have been publicised. The first is that one on the Koolhoven F.K. 55 fighter wherein the pilot is placed between the engine and the propeller gear box which is driven by extension shafting (9, 10). The propeller axis is offset, permitting forward cannon fire through the propeller shafts. The second installation is that one currently being tested by the U.S. Army Air Corps at the Materiel Division, Wright Field,

Dayton, Ohio, on a Curtiss YP-36 type pursuit aeroplane, Fig. 1. This latter experimental installation will be discussed in detail later.

It appears that the history of application of dual-rotation propellers to actual flying aeroplanes is fairly recent and that the total number of applications is few. It is safe to predict, however, that the future will see many high performance aeroplanes with this system of propulsion.

Limiting Aeroplane Velocity.

Lock (11), Fig. 21, presents a chart showing that at 530 m.p.h. a propeller similar to that used on the English Schneider Cup racing seaplane would be entirely covered by a compressibility shock wave. Similarly, Bock and Nikodemus in the discussion attendant to Fig. 17, reference 12, show that at 520 m.p.h., at 20,000 feet, a typical propeller would be entirely covered by a shock wave. In the first instance Lock used 0.95 c (0.95 times the velocity of sound) as the effective helical propeller tip speed. In the second instance 0.90 c was used. It is quite common practice in this country to use 0.95 c as the design limit for propeller tip speeds at the military r.p.m. rating.

550 m.p.h. was considered in this paper as the limiting aeroplane velocity for sustained level flight because computations using the latest available aerofoil data show that it should be possible to delay the compressibility shock wave to about this value for the entire propeller. Velocities above those at which the propeller is entirely covered by the shock wave are prohibited because of the enormous horse-power required to overcome the drag. No attempt is here made to estimate the limiting velocity of aircraft when methods of propulsion other than the conventional propeller are used. It is noted that the limiting velocity for conventional aeroplanes and methods of propulsion will probably be reached or approached only near sea level because of the decrease in the velocity of sound with altitude and its resulting effect towards hastening the compressibility burble.

Efficiency of Single-Rotation Propellers.

The three-bladed propellers used on present-day pursuit type aeroplanes are operating at values of blade angle (β at 0.75 radius) close to 45° at advance ratios (V/nD) of between 1.9 and 2.1. An inspection of Fig. 14, reference 13, shows that the propeller (with spinner) has its peak propulsive efficiency at $V/nD = 1.3$ at $\beta = 30°$. The loss in efficiency between this and $\beta = 45°$ is slightly under three per cent. Because velocity varies as the cube root of the efficiency, this means that aeroplanes at 350 m.p.h. are suffering about one per cent. loss in maximum velocity. The loss in efficiency, and hence performance, increases fairly rapidly as blade angles increase beyond 45°. It is essential at least to maintain or exceed, if possible, the present peak propeller efficiencies if aeroplane velocities are ever to approach 550 m.p.h.

Recent N.A.C.A. propeller data pertinent to in-line engine installations, which are increasingly common to-day, are included in references 13 and 14. It is important to note the effect that spinners have toward increasing the propeller efficiency. The spinner data that are presented show that a spinner has an increasing effect with increase in blade angle to maintain peak efficiencies to higher V/nD values and to prevent a rapid drop in the efficiency envelope at blade angles above 45°. (See Fig. 18, reference 13.) The spinner here used has the effect of raising the efficiency envelope from two to eight per cent. between values of β, varying from 20 to 60° over that envelope obtained with a bare hub. This difference in propulsive efficiency obtained with spinners is due solely to the elimination of hub drag and its adverse effect on propeller thrust. The actual hub drag appears to be more or less independent of blade angle (page 3, reference 13). As the blade angle increases, however, there is an increasing adverse effect on thrust and hence efficiency.

The above discussion of the adverse effect of hub drag on propeller efficiency and its alleviation by the use of spinners may appear to be irrelevant at this point. Its importance will be shown more clearly, however, in the following discussion on the efficiency of dual-rotation propellers. It should be noted that few experimental data on the effect of spinners are available.

EFFICIENCY OF DUAL-ROTATION PROPELLERS.

First credit for the development of even the simplest theory concerning the advantages to be derived from oppositely-rotating tandem propellers appears to go to Lanchester (5) (1918). Eiffel (15) (1919) deserves credit for the first systematic investigation and preparation of design data. The investigation of Durand and Lesley (16) (1919) was not carried to high enough advance ratios to show the advantage of the dual-rotation system tested. Weick (4) (1930) appears to be the first in this country to recognise the worth of Eiffel's data and the chapter on Tandem Propellers (4) adequately summarises that data. So far, however, propeller theory had not caught up with and explained the results obtained by Eiffel. Current theories apparently neglected to explore thoroughly the energy losses in the rotational slipstream at the higher advance ratios corresponding to blade angles above 45°. It was common practice to neglect rotational slip altogether. Computations for blade angles up to 45° showed the rotational losses to be only from two to four per cent. of the total energy (17, 18). In the years since 1930, however, advance ratios and blade angles have increased so rapidly that single-rotation propeller efficiencies have reached and passed their peak and the problem of maintaining high propeller efficiencies has brought forth theoretical work concerning the magnitude of these losses (12, 20).

One exception to the above remarks concerning failure to recognise the advantages of dual-rotation propellers may be made in recognition of the excellent work the Italians accomplished in the design and construction of the Macchi-Castoldi seaplane. Little information was available to the author concerning the preparation of propeller data for this aeroplane. Some wind tunnel testing of the propellers seems to have been done. Panetti (19) (1934) compares the theoretical treatment of the specific application of the dual-rotation propeller arrangement that was used to that using two motors back-to-back with tandem propellers separated by the two engines. It would seem that oppositely-rotating propellers were required to permit the negation of propeller torque to allow the twin-float seaplane to take-off. It has been reported that the English previously had to take-off the Schneider Cup racers at right angles to the wind because the unbalanced torque of the single-rotation propeller forced the opposite float into the water, necessitating a " water loop " of 90° into the wind. This manœuvre was hazardous and the Italian seaplane with greatly increased power could not use this technique. The dual-rotation installation was selected as being the most practical of the two possible arrangements. Panetti refers to the work of Pistolesi in 1922 for the theoretical background for his 1934 report. The Italians deserve a great deal of credit for their foresight in using dual-rotation propellers and in demonstrating their effectiveness in such a substantial manner. Their application may possibly have been born of necessity, however, and the propeller efficiency increase to have been incidental.

As previously pointed out (13) and many other data containing charts of efficiency *vs.* advance ratio for single-rotation propellers show the peak efficiencies to occur at values of V/nD between 1.2 and 1.4. It is noted that it was at approximately these values, specifically $p/D=1.2$, that Eiffel found increasing propeller efficiency with oppositely-rotating tandem propellers over the single-rotation propeller (4), Fig. 128. (p/D and V/nD differ only in that p/D includes the slip velocities.)

Losch, Kramer, Bock and Nikodemus (12), have made the most valuable contribution to date to the theory concerning the energy losses in the propeller slipstream. Data from this reference permits the construction of Fig. 2, which

shows the per cent. of axial and rotational energy losses in the slipstream of a propeller with infinite number of blades. Inspection of this chart gives an appreciation of why early theorists, who considered slipstream losses principally only up to $\beta = 45°$, dismissed the rotational losses as negligible. Weinig (20),

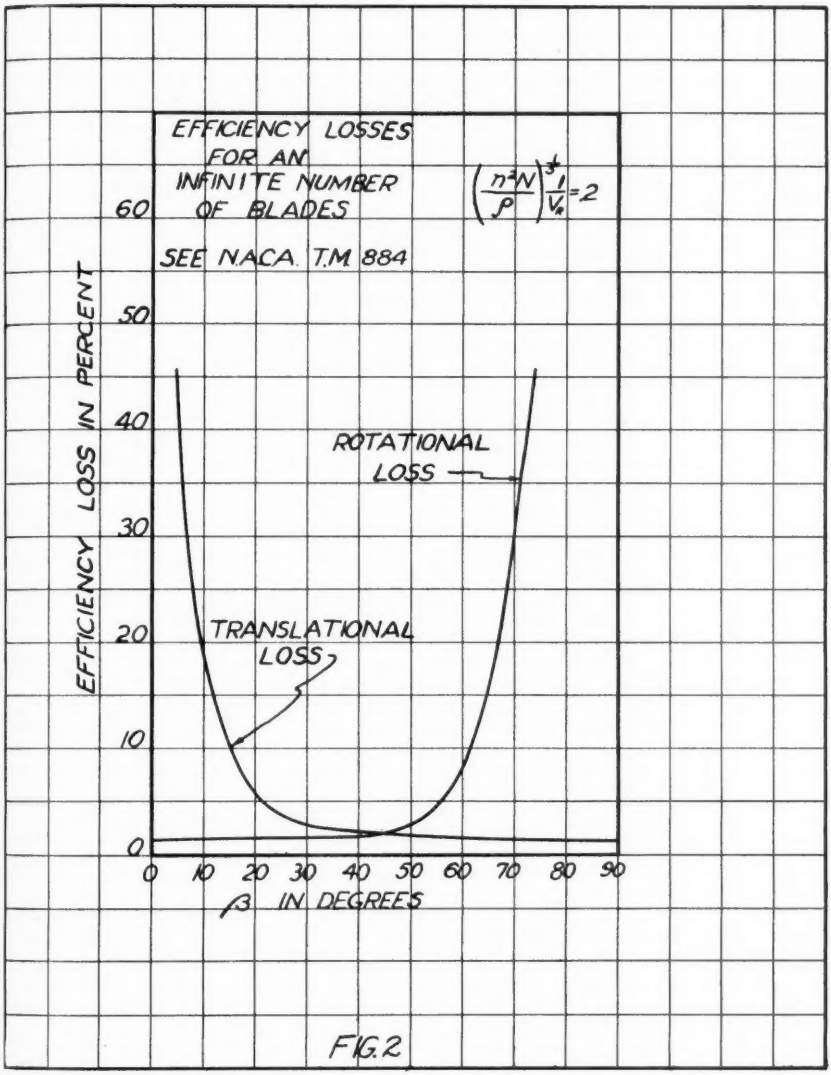

FIG. 2

in Fig. 12, Part IV, gives a convenient design chart for determining the relative efficiency gain that a dual-rotation arrangement gives over the single-rotation propeller at the same diameter and total number of blades. It is reiterated that this paper deals solely with this comparison in considering the relative efficiencies and advantages between the two arrangements.

Considering Fig. 2, the axial losses at low blade angles, corresponding to static thrust, are a maximum because thrust is a maximum. As velocity increases thrust decreases, until at high blade angles corresponding to maximum velocity, axial losses become a minimum. Conversely, rotational losses, varying with torque, are a minimum at low blade angles and a maximum at high blade angles. The relative increase and decrease of rotational and axial propeller losses with increase in blade angle can readily be visualised if the resultant reaction vector force on a blade element is resolved on to the thrust and torque axis for both a low and high value β. Inspection of this chart gives a realisation of the appreciable amount of energy it is possible to recover by the use of dual-rotation propellers. The pitch of the rear propeller is adjusted so that the rotational energy losses are absorbed. It is explained later how this can be effected in the paragraph dealing with hub design.

Reference 12 contains complete means of determining the relative effect any finite number of blades has on the propeller characteristics for single-rotation propellers. As all the losses, including rotational, can be separately computed for any set of desired design conditions, the advantages to be gained by the use of dual propellers over a single propeller can be determined. The data are not complete enough to permit quantitative values of efficiency to be used for design purposes, but they are valuable in furnishing relative efficiencies. Care must be taken in using the equations in this reference to check them dimensionally to insure using the correct values for distance, power, torque, etc., because the translation from the original is ambiguous and confusing in some detailed instances.

The following several paragraphs are devoted to a discussion of recently published propeller test data with and without spinners. The purpose is to point out the appreciable effects that spinners have in changing propeller characteristics. When these effects are fully appreciated it becomes apparent that the effect of spinners is the most important variable in evaluating otherwise directly comparable propeller test data.

The computations of Mills and McCauley* show that excellent agreement of the theory (12) with existing experimental design curves of efficiency against V/nD and Cs can be obtained. The theory is valuable in permitting existing envelope curves of efficiency to be extended to higher values of β, Cs and V/nD than those published (see Weick (4) for definitions of Cs, etc.). An attempt was made to determine from experimental data consistent values of the coefficients involved in the inclusion of profile drag and dependent upon the coefficient of advance. (See page 44, reference 12.) Although any given curve could be extended by taking existing points on the envelope and solving simultaneously for the unknown coefficients, these coefficients so determined were peculiar to the type of nacelle, size of hub, type and size of spinner, etc., tested. As pointed out before, most of the existing propeller design data are for propellers without spinners. No complete series of investigations has been made to date in this country to determine fully the effect of hub drag on propeller characteristics. References 13 and 14 give an indication of how severely hub drag may affect these characteristics. The majority of the military aeroplanes in this country have their hubs covered with spinners. It is important that future propeller testing includes the complete effect of the spinner at all blade angles tested, and in addition that these blade angles be carried to as high a value as is practical.

Fig. 3 shows superimposed curves of 2, 3 and 4-bladed propellers from Lesley's Stanford tests (21, 22) of isolated propellers. Reference 22 includes data showing

* Acknowledgment is gratefully made of the assistance furnished by R. H. Mills and J. W. McCauley, Propeller Laboratory, Wright Field, in checking the theory developed in reference 12. The results of their extensive studies will undoubtedly be presented at a later date as soon as the necessary experimental test data necessary for check can be obtained.

that the drag of a two-bladed hub so adversely affects the thrust that an increase in efficiency of $1\frac{1}{2}$ per cent. over the efficiency with the bare hub is obtained when a spinner is used. This amounts to a $3\frac{1}{2}$ per cent. increase for the three-bladed hub. There is still a further increase to about 4.1 per cent. for the four-bladed hub. Because the effect of spinner on efficiency was only determined for one blade angle setting (22) it was necessary in order to plot the upper curves of Fig 3 to attempt to correct for the effect of spinner in the manner detailed on page 3 of reference 13. If this method of correction had been correct for isolated propellers, a nicely spaced family of curves should have resulted. It is noted that there is no definite family. To eliminate properly hub drag effects it is necessary that the tests be re-run with spinners at all blade angles. When hub drag is eliminated in the testing of isolated propellers a family of curves results

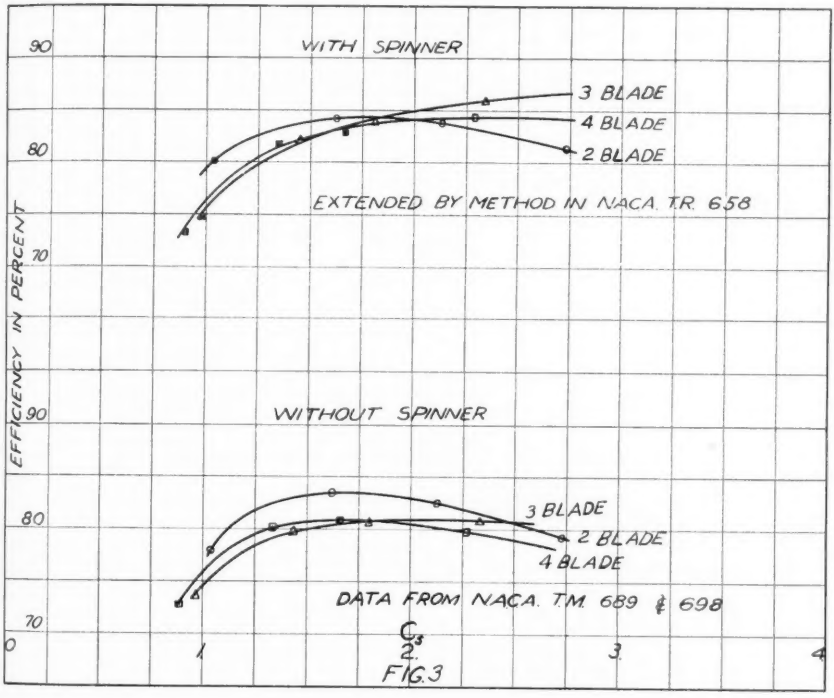

FIG. 3

somewhat similar in appearance to those obtained by Lock, Bateman and Nixon (23), in which tests the effect of solidity for two and four blades was determined by placing the blades around a cylinder which served as a spinner, eliminating hub drag and making the propeller characteristics directly comparable. Propeller theory (12) gives a family of curves for isolated propellers similar in appearance to those obtained in reference 23.

Biermann and Hartman, on pages 18 and 19 (reference 24), compare the efficiency curve for propellers with 2, 3 and 4 blades mounted ahead of a liquid-cooled engine nacelle. Here again the curves do not plot in a family. The reason, undoubtedly, is due to the difference in hub drag and its effect on thrust for the various propellers. Biermann and Hartman point out that increase in solidity by merely adding blades does not have, by far, the adverse effect on efficiency that is commonly thought. Although there is very little difference in

the efficiency curves of Fig. 35 (reference 24), the four-bladed propeller naturally has in general the lowest efficiency. Should hub drag effects be eliminated by using a common spinner, it cannot necessarily be expected that a well defined family of curves would result because of the effect of the after body (engine nacelle). No great difference in the envelope curves would be expected, however, for as Biermann and Hartman state (24), " Increasing the number of blades decreases the tip loss, which tends to offset the bad effect of the increase in solidity." Modern theory (12) emphasises this same effect. It would be very interesting if the tests (24) could be re-run with a common spinner in order to check the theory because coefficients can be calculated from test data that take into account all kinds of interference effects.

Derring and McHugh (25) compare apparent, propulsive and net propeller efficiencies with different ratios of nacelle diameter to propeller diameter. The increase in both propulsive and net efficiency is considerable when a spinner is used to eliminate hub drag. These tests included mounting the isolated propeller on an extension shaft and measuring its apparent efficiency. Because there is no body immediately behind the propeller, it would be expected that the apparent efficiency of the propeller alone would be greater than the net efficiency of any combination of nacelle and propeller. This was not the case. Pictures, however, indicate that the isolated propeller did not have its hub covered by a spinner. Thus the three-bladed hub drag and its effect on thrust and efficiency is included in the apparent efficiency of the isolated propeller. It is believed that if a spinner of the diameter of the extension shaft housing were tested with the isolated propeller that its apparent efficiency would be greater than any net efficiency for the various nacelle-propeller combinations tested.

Lesley (21) compares the efficiency of a dual-rotation propeller system with a total of four blades to that of a single-rotation propeller with the same number of blades. It was determined that the envelope efficiency increase in favour of the dual-rotation propellers varied from 0.5 to 1.5 per cent., increasing directly with blade angle. Angles up to 45° only were tested. The propellers, however, did not have the hubs covered by a spinner. The adverse effect on thrust of the four-bladed hub should be so much more compared to that of the two two-bladed hubs in tandem that these data are not directly comparable. In order to obtain directly comparable data between propellers of different solidity ratios and between dual and single-rotation propellers of equal solidity, it is necessary that a series of tests, somewhat similar to those described below, be conducted. Existing theory has been well substantiated by the limited existing experimental data, and data from these new tests should permit a further accurate check of the theory.

Tests are suggested of the following propellers:—

1. Two-bladed with average planform (single rotation).
2. Two-bladed with blades widened 50 per cent. (single rotation).
3. Three-bladed with average planform (single rotation).
4. Three-bladed with blades widened 33¼ per cent. (single rotation).
5. Four-bladed with average planform (single rotation).
6. Four-bladed with blades widened 50 per cent. (single rotation).
7. Four-bladed with average planform (dual rotation).
8. Four-bladed with blades widened 50 per cent. (dual rotation).
9. Six-bladed with average planform (single rotation).
10. Six-bladed with average planform (dual rotation).
11. Eight-bladed with average planform (single rotation).
12. Eight-bladed with average planform (dual rotation).

The eight-bladed propeller will have the largest hub. It is essential that this be covered by a spinner. All of the other propeller hubs should have the same diameter as the eight-bladed one and their hubs should be so designed that a constant diameter spinner can be used with all propellers. The cylinder arrange-

ment used by Lock, Bateman and Nixon (23) would be very desirable and should be an easy installation to effect. The data so obtained would permit direct comparison of the effect of number, solidity and arrangement of blades, with no other variables such as hub drag involved.

An investigation of this sort is urgently needed and would be a most valuable and timely contribution to propeller and aerodynamic knowledge. The specific data could be used directly for pusher and extension shaft propeller installations, of which there are increasing numbers of design studies. Although the above dissertation concerning the importance of spinners may appear irrelevant to this paper at first glance, a study of the references will show the majority of existing propeller data to be really incomplete as far as permitting the evaluation of the adverse effect of hub drag on thrust and efficiency, particularly at the higher blade angles. One of the main objects of this paper is to emphasise this effect and the need for additional data. Only by this means can quantitative design data be obtained to permit proper evaluation of the worth of dual-rotation propellers.

Six and eight-bladed propeller tests are included in the programme because of the present tendency toward increasing the number of blades. Reference 26 illustrates an English dual-rotation propeller with six blades displayed at the Royal Aeronautical Society's Show, May, 1939. This propeller is constant speed and full feathering. There has been at least one six-bladed dual-rotation propeller in the process of design and construction in this country for the past three years combining these control features. Recently an aeroplane design study came to the author's attention which required a dual-rotation system with a total of eight blades. It is evident that designers of to-morrow's high performance aeroplanes are not blind to the multiple advantages afforded by the use of dual-rotation propellers. Adequate experimental data must be made available for their use.

Flight Tests on Pursuit Type Aeroplane Equipped with Dual-Rotation Propellers.

During the past 18 months comparative testing of a dual-rotation propeller system with three and four-bladed single-rotation propellers has been in progress at the Materiel Division, Wright Field, Ohio (Fig. 4). Accent was placed on the comparative performance in take-off, climb and maximum velocity between the four-bladed dual-rotation and four-bladed single-rotation installations. The tests were made with the propellers installed on an early model of the Curtiss P-36 type pursuit aeroplane. The gearing for the dual-rotation tests was loaned by Pratt and Whitney Aircraft and the ground adjustable propellers were loaned by Hamilton Standard Propellers, Fig. 1.

No controllable constant-speed propeller was available for the dual-rotation flight tests, hence these flights and the comparative four-blade single-rotation flights were made at the same blade angles in fixed pitch. The highest blade angle at which it was possible to get off the ground in fixed pitch was 32°. This relatively low blade angle did not permit level flight velocities over 300 m.p.h. to be reached because the limiting engine r.p.m. prevented the use of rated engine power. Inspection of Figs. 10 and 11, reference 21, shows so little difference in efficiency between the dual and single four-blade propellers up to blade angles of 32° that no difference in performance was expected. Tests substantiated this expectation in that no difference within the flight test accuracy in take-off, climb or maximum velocity was obtained. Tests were made at five different blade angle settings between 15 and 32°. The limit in blade angle made the tests somewhat disappointing because high enough values of V/nD could not be reached to show the full advantage of dual-rotation propellers toward increasing the maximum velocity of the aeroplane. It is seen that for velocities under about 350 m.p.h., little evident improvement can be expected because the

accuracy of flight test measurements being about one per cent. requires more than a three per cent. gain in propeller efficiency to show consistently measurable differences in performance.

Additional tests were made with the same propeller blades in constant-speed three and four-bladed hubs of Curtiss Propeller Division design to check the effect on take-off, climb and maximum velocity due to the difference in solidity between three and four blades. Again no differences were found within the limits of flight test accuracy. This was to be expected in light of the little difference in efficiency over the flight range tested between three and four-bladed propellers as demonstrated by Biermann and Hartman (24).

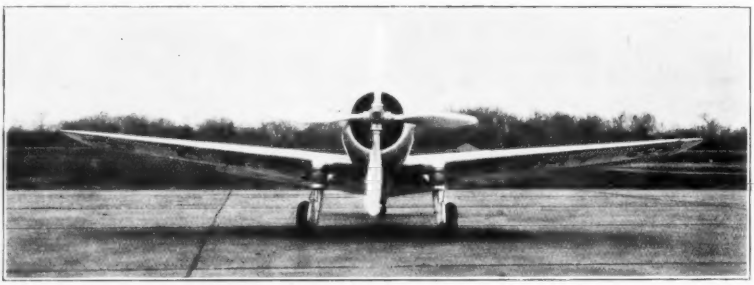

FIG. 4.

The effect of dual-rotation in negating engine propeller torque was very noticeable. The vertical fin was left in its conventional off-centre position for these tests. It was only necessary to offset the rudder trim tab the amount needed to balance the offset vertical fin. Because there was no torque, all manœuvres to either right or left were the same; that is, they required the same control forces. The aileron controls were particularly soft in contrast to the single-rotation installation and manœuvres such as slow rolls were identical in both directions and easier to make. There was a remarkable freedom from vibration throughout the aeroplane with the exception of one period at about 2,200 engine r.p.m., at which the control stick happened to be in resonance and at which r.p.m. a slight beat was audible. This beat was not objectionable and the control stick movement was not excessive. The noise due to blade passage was not otherwise noticeable, even by ground observers. The flight testing was very gratifying from these above-mentioned aspects. The majority of pilots who commented on the installation after flying the aeroplane remarked about the smoothness of the engine and aeroplane as a whole.

There was some concern previous to installation of the gearing and propellers on the aeroplane as to the effect that vibration due to blade passage would have on both the stresses in the solid aluminium blades and on the torsional characteristics of the engine. The combination was mounted on an engine torque stand and torsiograms were taken, using a Prescott torsiometer. Comparison with torsiograms made with the conventional single-rotation gearing and propeller showed no appreciable difference in amplitude of vibration so far as the engine was concerned. Blade passage could not be detected in the records. The combination was so mounted in the torque stand that the blades passed at one point directly in front of an observation window. Stopping the motion by means of a rotoscope showed no visual deformation or bending of the blade tips as they passed each other. These tests and observations were encouraging and after 50 hours of endurance running a tear-down inspection showed the gearing and engine to be in first class shape, and installation on the aeroplane was then made.

After the flights were completed, equipment was installed in the aeroplane to permit the measurement of propeller stresses in flight. These stress measurements were made by using carbon resistance strip gauges cemented to the blades. Leads were cemented from the pick-up gauges to the hub to collector rings.

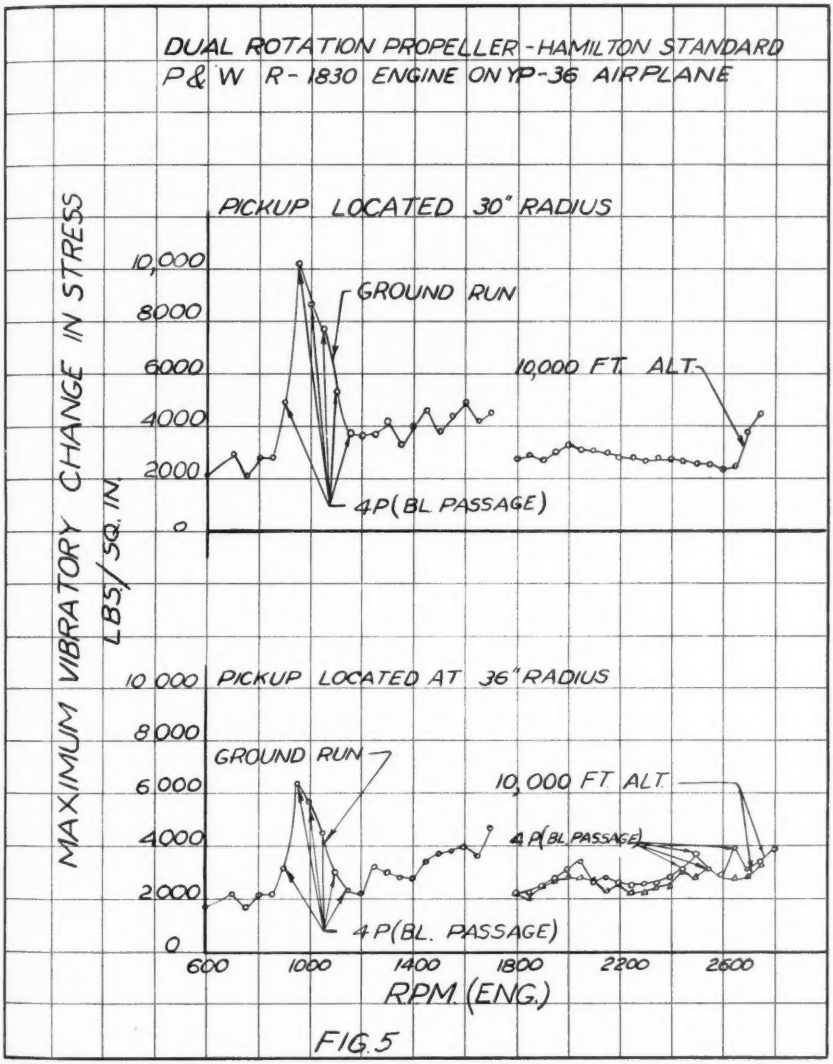

FIG. 5

As the stresses varied, the resistance of the gauges varied and this variation was recorded on photographic film in a recording oscillograph mounted in the baggage compartment of the aeroplane. The resistance gauges were of the type developed by Hamilton Standard Propellers, and the details of the test method, including interpretation of the results, are thoroughly covered by

Caldwell (27) and Kearns (28). Fig. 5 shows plots of two typical records showing the highest stresses measured. The stresses indicated represent total amplitude of stress variation from the mean. Blade passage, four times propeller r.p.m. (4 P), can be recognised as illustrated. The highest stresses measured, however, were not found in flight, although they were due to mutual blade passage. These occurred during the ground run at about 900 engine r.p.m. This condition would normally only occur in flight during the last part of the landing approach. It would be of such short duration and so little power would be involved that no serious results would be expected. The resonance previously mentioned at 2,200 r.p.m. was not reflected in any increase in stress. The maximum total stress measured was about 10,000 lbs. per sq. in. and occurred at such a low r.p.m. on the ground that very little power was being absorbed by the propeller. With present experience the value of 10,000 lbs. per sq. in. is considered the limiting stress for aluminium alloy for the blade sections proper. All of the stresses in flight were well within allowable limits. It may be concluded, therefore, that there need be no concern over the structural safety of dual-rotation propellers as affected by vibrations due to blade passage if resonance is avoided.

Relative Advantages and Disadvantages, Including Design Problems.

There are numerous advantages to be gained by using dual-rotation propellers in those high performance aeroplanes which are so highly powered as to require propellers with four or more blades. As suggested earlier an increase in propeller efficiency throughout the entire flying range is not the only advantage to be gained by their use. When tests similar to those suggested are made available an accurate estimate of this increase in efficiency can be made. Theory permits a close approximation of the relative value to-day. The other benefits are not so tangible, but their accumulated effect is of the proper order and only detailed study of a particular aeroplane design will permit an estimate of their magnitude.

Benefits other than increased propeller efficiency and performance include the negation of propeller torque reaction. This will permit smaller spans for single-engined aeroplanes that are so fast that small aspect ratios have no appreciable effect on maximum velocity. This shorter span should permit a lighter wing for a given design load factor due to increased structural efficiency. Improved lateral control should result, and because only enough aileron control is needed for the design manœuvres, the ailerons, their fittings and controls should show a weight saving. Because there will be no rotation in the slipstream, symmetrical flow over the wing root fillets and tail surfaces is assured. This will improve both lateral and longitudinal stability. The lessening of turbulence in the slipstream will help delay the point of separation on those surfaces affected by the slipstream. This is a drag improvement toward increased velocity. The vertical fin need not be offset to counteract torque, hence this increment of drag is eliminated as is that drag due to offset rudder trim tab to compensate for the normal off-centre vertical fin. These latter improvements in drag are small, but are in the right direction.

The main objection to dual-rotation propellers is the increased weight of the necessary gearing. An estimate made by one engine company of the increase in weight necessary to provide dual propeller drives on an engine with 2,000 h.p. military rating is 75 pounds. Depending upon the specific design of rotating propeller, studies show that dual-rotation propellers will weigh no more than the equivalent single-rotation propellers when there is a total of six or more blades. The Engineering Projects four-bladed, dual-rotation constant-speed propeller design, Fig. 6, weighs about 80 pounds more than an equivalent four-bladed single-rotation propeller. Six-bladed propellers, however, are expected to weigh about the same, and eight-bladed ones should show some saving in favour of dual-rotation. Some gearing installations, particularly extension shaft

propeller drives, show that dual-rotation gearing may not involve any increase in weight and in one design study there was even an estimated saving. It may be concluded that if there is any increased weight in the combined dual-rotation gearing and propeller that it will be more than compensated for by increased efficiency and hence performance for small single-engined aeroplanes. The increased efficiency at cruising will permit an overall increase in range for the larger aeroplanes because any added weight will be compensated for in the first few hours of flight by petrol saved for a given thrust horse-power.

Any objection to the use of dual-rotation propellers because of the cost of propellers and gearing is answered by the consideration that this matter is a relative one depending on the quantity of units manufactured. Should dual-rotation be standardised for any given engine model then the cost of such gearing and propellers should be no greater than for single-rotation gearing and a larger one way hub.

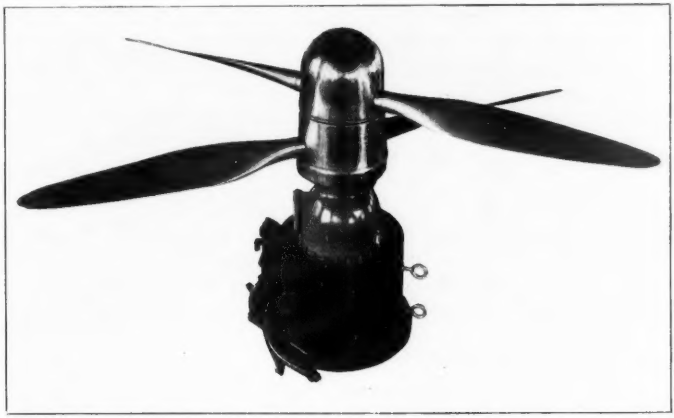

FIG. 6.

There are several design details involved with dual-rotation propellers that deserve mention. Lesley (21) shows that the relative spacing of the propellers has no appreciable effect on efficiency. This permits as close spacing of the front and rear propellers as is possible while making allowance for about one inch blade clearance in the feathered position for the widest blade it is planned to use. Close spacing is most efficient for weight and strength reasons. It permits the use of blades of identical diameter, plan form and pitch distribution. The only effect on blade construction is that the direction of rotation is different. This involves extra blade dies unless opposite rotation requirements have already made them necessary. From the practical mechanical standpoint, governing of the two propellers and the relative adjustment of the pitch of the two propellers is simpler the closer the spacing. This latter item imposes the hardest problem in the design of a constant-speed controllable dual-rotation propeller.

Lesley (21) shows that at low blade angles corresponding to take-off settings ($\beta = 15°$) both front and rear propellers have the same setting. However, at a setting of $\beta = 45°$ for the front propeller it is necessary in order to equalise torque that the rear propeller be set lower 1.1° ($\beta = 43.9°$). This increment increases almost linearly with increase in blade angle. It is simply explained that the differential pitch of the rear propeller increases with increasing blade angles because the rotational energy absorption grows greater. The rear setting is lower than the front because the angle of attack has been decreased due to the

inflow components of both propellers combining with the rotational component of the front. Another conception is furnished by the fact that the rear propeller, in absorbing the rotational power losses, is in effect being windmilled and that only a lower blade setting is required because less power has to be put into it to equalise the torque and power of the front propeller. Both propellers are rotating at the same speed because the drive shafts must be positively geared together at all times. This is absolutely necessary so that torque will be equalised for all conditions of flight to allow for partial engine failure. The Italians made this mistake in driving each propeller of the Macchi-Castoldi racer by a separate engine. Positive gearing is also necessary to permit synchronised machine gun fire. This problem for a dual-rotation propeller of six blades is the same as for a three-bladed single-rotation propeller if the line of fire coincides with a line of blade passage.

There are several possible approaches in attacking the problem of adjusting the differential pitch setting so that the rear propeller will increase its increment as the pitch of the front propeller increases. The same holds in case the rear propeller is the governing propeller.

1. The pitches may be kept the same or a set differential may be maintained. This means that some unbalance in torque will result at any flight or power condition other than that set. This unbalance should not be too much of a penalty if the differential is designed for torque balance at operating (cruising) pitch.
2. The pitches may be varied from one propeller to the other mechanically, as with cams. Governor controls would be attached to one propeller, and the interconnecting cam or linkage would keep the other at the proper pitch setting to insure torque balance.
3. A torque measuring element could be put in each propeller drive. A governor would control one propeller and any unbalance in torque would cause the interconnected torque measuring device to adjust the other until balance was reached.
4. A torque measuring device could be installed on the engine mount. A governor would control one propeller and as unbalance resulted the torque element would adjust the other until balance was effected.

CONCLUSION.

The comments herein are the result of a detailed study of data that the writer has been collecting for the past five years. The writer is certain that if anyone will surround himself with the references noted and study them carefully that he cannot help but come to the same conclusions concerning dual-rotation propellers as are outlined in the abstract and introduction at the beginning of this paper. This exposition will have served its purpose if it stimulates sufficient interest and action to obtain the experimental tests now so sorely needed to check the benefits evidenced by the existing theory and data.

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SOME ECONOMIC ASPECTS OF TRANSPORT AEROPLANE PERFORMANCE.

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*Presented at the Aeroplane Design Session, Eighth Annual Meeting, I.Ae.S., New York, January 26, 1940.**

Abstract.

Total air transport operating costs are divided into three general classifications: (1) Significant operating costs which are defined as those resulting from the flight of an aeroplane or those affected by variation of aeroplane size, power, initial cost, and aerodynamic efficiency. Equations for the development of significant costs are presented. (2) Passenger service costs which are defined as those which vary with the number of passengers aboard an aeroplane are enumerated. (3) Overhead costs in air transportation are also dwelled upon and it is concluded that these costs change their proportion to significant costs when the physical and performance characteristics of the aeroplane being considered change.

The marked effect on significant cost of varying aeroplane utilisation is brought out. Utilisation is also shown to be chiefly a function of trip length, with block speed, seasonal schedule variation and other factors being secondary functions.

The effect on significant cost of varying block speed either by increasing cruising power or improving aerodynamic efficiency is investigated for one type of transport aeroplane. Increased block speed obtained by increasing cruising power is found to increase significant cost very rapidly. Increased block speed obtained by improving aerodynamic efficiency is found to decrease significant cost appreciably and relatively large increases in aeroplane first cost are found to be justified if aerodynamic efficiency is improved. The adverse effect on significant cost of increasing trip length is investigated. The effect of changing specific fuel consumption is discussed.

It is pointed out that economic factors apart from those associated with fundamental aeroplane design and performance, such as interior arrangement, safety records, competition and general economic conditions, play the major role in the economic outcome of air transportation.

Part I.

Development of Significant Cost Equations.

The purpose of Part I of this study is to develop and explain the several cost equations which as a group comprise the significant cost of transport aeroplane operation as defined in the succeeding section, and to dwell briefly on the nature of overhead costs.

Significant or Direct Cost Equation.

Significant or direct costs may be defined as those costs resulting from the flight of an aeroplane and those costs affected by aeroplane size, power, initial cost, as well as aerodynamic efficiency.

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After a study of the operating and economic characteristics of two known types of aeroplanes, a series of operating cost equations have been devised taking into consideration most of the pertinent and influencing cost factors. These equations are used in the determination of significant costs of operation of the transport aeroplanes investigated in Part II of this study.

It is difficult and probably impossible to state in equation form a series of " fool proof " factors which will measure or project significant costs accurately and universally on all types of air transport aeroplanes known or on the horizon of the future. In the first place, maintenance and overhaul costs vary from year to year on the same equipment within the same company. The practices of the major companies are likely to be different from those of smaller feeder line organisations. For one thing, elaborate overhaul and repair depots are not economical until the volume of operation is considerable. Also complication of structure, including supercharged cabins, interior arrangements, etc., which affect first cost, depreciation, and maintenance are likely to differ on large transport aeroplanes compared with smaller ones. These and other contingencies of similar nature make it difficult to express costs in a universal manner.

There is offered, however, immediately following a series of significant operating cost equations with sufficient explanation attending each equation for its understanding. Each of these equations is given first in general terms and then with the specific constants assumed in this study inserted. All equations are expressed in terms of cost per ton mile of payload capacity which is considered the significant cost.

SYMBOLS.

V_b = Block speed, m.p.h.
L = Payload, tons.
N = Number of engines.
M = Number of seats.
P = Total cruising b.h.p., h.p.
U = Utilisation per year per aeroplane, hr./yr.
C_t = Total cost of aeroplane and engines, dollars.
C_a = Cost of aeroplane less engines, dollars.
C_e = Cost of one engine, dollars.
W_a = Weight of aeroplane less engines, lb.
W_e = Weight of one engine, lb.
Y = Number of cylinders per engine.
C_m = Cost per ton mile of payload capacity, dollars.

The subscript " zero " added to any of the above symbols indicates that the value is known and therefore must be taken from transport aeroplanes whose economic characteristics are known.

FUEL COST INCLUDING TAX.

$$C_m = \frac{(\text{Fuel cost in dollars per gal.})\ (\text{cruise sp. cons.})\ P}{6\ V_b L} = (0.127)\ (0.45)\ P/6\ V_b L \quad (1)$$

The determination of fuel cost is simple and straightforward unless extremely accurate results are desired, in which event it is necessary to consider individually the additional fuel used for engine run-up, taxi-ing, take-off and climb. However, the use of block speed instead of level flight speed in the above equation gives a very close approximation to true fuel costs.

It is estimated 90 octane fuel would be obtainable on a volume contract basis at prices ranging from $0.10 to $0.145 per gallon (including tax) according to freight rates and location of airport of delivery in United States. For the purpose of this study an average price including tax of $0.127 per gallon is used.

The specific fuel consumption of 0.45 lb. per b.h.p. hr. used above is approximately the best that can be obtained with late type engines when operated in the neighbourhood of 50 per cent. of take-off power.

OIL COST INCLUDING TAX.

$$C_m = \frac{(\text{Oil cost in dollars per gal.})\ (\text{cruise sp. cons.})\ P}{7{\cdot}5\ V_b L} = (0.4)\ (0.012)\ P/7{\cdot}5\ V_b L \quad (2)$$

A major air transport operator will be able to negotiate oil contracts which will deliver oil to airports over a large geographical area at a cost including Federal tax from $0.35 to $0.45 per gallon. For the purpose of this study, the average cost of oil per gallon including tax is assumed to be $0.40.

A standard practice of operators is to drain engines of all oil at periodic intervals measured in terms of engine running hours. A reasonable estimate of this draining loss has been found to be 20 per cent. of the oil actually burned.

The approximate cruising specific consumption for engines of known characteristics is 0.01 lb. b.h.p. hr. Hence, the equation above uses a specific oil consumption of 0.012, which includes the additional 20 per cent.

AEROPLANE DEPRECIATION COST.

$$C_m = \frac{(C_a - \text{Salvage})}{C_a} \times \frac{C_a}{(\text{Depreciation period in years})\ U\ V_b L} = 0.90\ C_a/6\ U\ V_b L \quad (3)$$

Air transport accounting practice in general calls for a straight line depreciation method for aeroplanes after a salvage or residual sum has been taken from the first cost. The above equation assumes this straight line method over a period of six years with a salvage value of 10 per cent. of original cost. Original cost entering into the depreciation problem is taken as the cost of the aeroplane complete including propellers, instruments, and radio, but less engines.

How to handle propeller depreciation raised a question, for a propeller is divided into two main parts differing in length of life. It has been found that an aeroplane will wear out perhaps three sets of blades, but the hub will remain in use during almost the entire life of the aeroplane. In other words, the hubs approximate aeroplane life and the blades engine life. The propellers were considered part of the aeroplane for two reasons: (1) For purposes of simplification; and (2) because this practice has been and still is followed by air transport accounting departments.

ENGINE DEPRECIATION COST.

$$C_m = N C_e/(\text{engine life in hours})\ V_b L$$
$$= 4\ C_e/5{,}000\ V_b L \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Air transport accounting practices generally accept engine running hours as a basis for depreciation and therefore hourly engine depreciation is simply the engine first cost divided by the engine life in hours.

No allowance for salvage value is placed in the equation above, although experience dictates allowance should be made if hours of life are estimated to be less than 5,000. Such salvage inclusion could be made in the same manner as shown in the aeroplane depreciation equation.

Large operators usually purchase engines in fair sized groups, and there is now a rapidly growing school of thought within the air of transport industry which proposes that engine costs be grouped and depreciated on a straight line calendar year basis similar to the method used to depreciate aeroplane costs. From an operations and maintenance view, however, it will probably always be necessary to keep individual engine time.

AEROPLANE OVERHAUL AND REPAIR COST.

$$C_m = \{ \text{Labour} \times (M/M_o + N/N_o) + \text{Material} \times (W_a/W_{ao} + C_a/C_{ao}) \} / 2\ V_b L$$
$$= \{ 2.48\,(M/21 + N/2) + 2.00\,(W_a/13{,}800 + C_a/100{,}000) \} / 2\ V_b L \quad . \quad (5)$$

Aeroplane overhaul and repair cost characteristics on two types of aeroplanes were known by the authors. By inspection of these characteristics important relationships were determined as to the material and labour functions of overhaul and repair.

Cost per hour flown of labour and material are represented by $2.48 and $2.00, respectively, taken from experience concerning a particular type of aeroplane. The 21, 2, 13,800 and 100,000 indicate, respectively, number of seats, number of engines, weight empty less engines, and cost in dollars of the aeroplane whose overhaul and repair costs are as stated above. Interior complications and arrangement expressed as seats, M, and engine change expressed as number of engines, N, in the equation, are important functions of labour costs. Aeroplane weight empty less engines, W_a, and aeroplane cost less engines, C_a, are important functions of material costs. Each function appearing in the equation is given one-half weight; hence the 2 in the denominator.

There are other aeroplane overhaul and repair costs which usually appear as such, not included in the above equation. These are the cost of special aeroplane revisions or projects not capitalised, and purchase and installation of de-icer boots. Such costs might increase the routine costs covered by the equation by between 10 per cent. and 25 per cent., but they are omitted from direct costs in this study and considered as being a part of overhead costs.

ENGINE OVERHAUL AND REPAIR COST.

$$C_m = (N/N_o)\,[\text{Labour} \times (W_e/W_{eo} + Y/Y_o) + \text{Material} \times (W_e/W_{eo} + C_e/C_{eo})]/2\ V_b L$$
$$= (N/2)\,[1.0\,(W_e/1{,}400 + Y/14) + 2.25\,(W_e/1{,}400 + C_e/12{,}000)]/2\ V_b L \quad (6)$$

As was the case with aeroplane overhaul and repair, overhaul cost characteristics for engines were known for two types of engines. Important relationships here were also established between costs and labour and costs and material.

Known labour and material costs are represented by $1.00 and $2.25, respectively, per aeroplane hour flown. The 1,400, 14, and 12,000 indicate, respectively, engine weight, number of cylinders per engine, and unit cost of engines whose overhaul and repair costs are as stated above. Engine weight, W_e, and number of cylinders, Y, are found to be important considerations in determining labour costs, whereas weight, W_e, and first cost, C_e, are important functions of overhaul material costs. Inasmuch as the known labour and material costs are on an aeroplane hour basis for an aeroplane having two engines, this whole section is bracketed and multiplied by the ratio $N/2$ to make the equation applicable to an aeroplane having a different number of engines.

As in the case of aeroplane overhaul and repair, each function is given one-half weight in the equation; hence the 2 in the denominator.

AEROPLANE AND ENGINE GROUND SERVICE COST.

$$C_m = (\text{Labour} + \text{supplies})\ (2\,N/N_o + W_a/W_{ao})/3\ V_b L$$
$$= 5.50\ (2\,N/2 + W_a/13{,}800)/3\ V_b L \quad . \quad . \quad . \quad . \quad (7)$$

Aeroplane and engine ground service cost as expressed in the above equation includes the labour cost for cleaning and washing the aeroplanes, both outside and in, checking engines, and checking aeroplane structure periodically. It also includes the cost of some cargo loading labour. Supply costs include cost of grease, waste, cleaning compounds, perishable tools, etc.

Before further explaining the above equation, it might be well to dwell briefly on the basic nature of this type of cost. It is an uncertain cost and is difficult to associate with any particular aeroplane characteristic such as weight or power. Operations men are not sure of the reasons for fluctuations of aeroplane service

costs and hesitate to predict what a fleet of large four-motored craft might require in the way of service. The irregular service costs with regard to the operation of two known types of aeroplanes indicate that the scepticism of operations and line service experts contacted is well founded.

Some engaged in aeroplane economic studies have ignored it as a significant cost and considered it as overhead. For the purpose of this study, however, an equation is offered which at least clings to a cost base drawn from experience. The $5.50 in the equation represents the service cost per aeroplane hour flown for a known aeroplane and operation. The cost of aeroplane service is assumed to vary with the number of engines, N, and the weight of the aeroplane empty, W_e. Inasmuch as the engines require frequent oil, grease, and electrical service, the engine function expressed as $2\,N/N_e$ is given twice the weight given to the aeroplane weight function; hence the 3 in the denominator.

CREW PAY AND INSURANCE COST.

FIRST PILOTS.

$$C_m = (1 + \text{Ins. rate})\,[(\text{Day-night factor})\,(3.55 + 0.00667\,V_b) + (\text{dollars per mi.})\,(V_b - 100) + \text{Annual base pay/Annual flying hours}]/V_bL$$
$$= 1.07\,[1.25\,(3.55 + 0.00667\,V_b) + 0.01\,(Vb - 100) + 2{,}400/850]/V_bL \qquad (8)$$

OTHER CREW MEMBERS.

$$C_m = (1 + \text{Ins. rate})\,(\text{Annual pay at } V_{bo}/\text{Annual flying hours})\,\{(1 + V_b/V_{bo})/2\}/V_bL$$
$$= 1.07\,\{(3{,}700 + 2{,}400)/850 + (1{,}620 + 1{,}420)/900\}\,\{(1 + V_b/160)/2\} \qquad (9)$$

INSURANCE PORTION OF EQUATION.

It is reasonable to assume that a major air transport operator would carry the following insurance on its flight crew: (1) Compensation Insurance, (2) Group Life Insurance, and (3) Federal Old Age Benefits and Unemployment Insurance.

After a study of insurance as related to flight pay-roll costs, it is estimated that the cost of the above insurance will approximate 7 per cent. of total flight pay-roll costs.

FIRST PILOT'S PAY.

Pilots in charge of transport aeroplanes are paid in accordance with a scale as set down in ruling No. 83 of the Federal Labour Board. It is composed of three portions: A base or fixed pay; an hourly rate; and a mileage differential. The above equation considers all three portions.

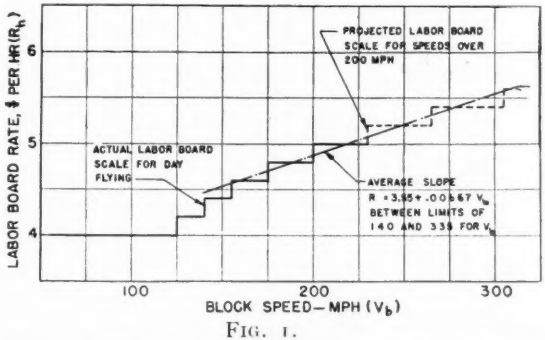

LABOR BOARD RATE, $ PER HR (R_h)
6
5
4
PROJECTED LABOR BOARD SCALE FOR SPEEDS OVER 200 MPH
ACTUAL LABOR BOARD SCALE FOR DAY FLYING
AVERAGE SLOPE R = 3.55 + .00667 V_b BETWEEN LIMITS OF 140 AND 335 FOR V_b
100
200
300
BLOCK SPEED—MPH (V_b)

FIG. 1.

Labour Board rate of hourly pay for first pilots as affected by block speed.

The hourly rate is dual, one for day flying and one for night flying. The night rate is always 50 per cent. greater than the day rate; hence the factor 1.25 in the equation which assumes a half day and half night operation. The expression $(3.55+0.00667\ V_b)$ covers the hourly rate in terms of block speed as illustrated in Fig. 1.

The Labour Board scale of pay takes cognisance of speeds up to only 200 m.p.h. It is necessary, therefore, to extrapolate the curve in Fig. 1 to speeds well beyond the Labour Board limit in order to provide an hourly pay basis for the aeroplanes compared in this study.

The pilot's pay mileage differential for aeroplanes of the velocity investigated in this paper will automatically allow $0.01 per mile for all miles above 100 flown during each hour. This relationship can be expressed as $0.01\ (V_b-100)$.

Pilot's base pay was fixed at $2,400 per annum for 850 hours of flying time.

The Labour Board plan for pilots' pay is the result of a compromise between the Airline Pilots' Association and company management. It is an attempt to divide the theoretical economy in pilots' pay derived from additional aeroplane speed between the pilots and the company involved.

Other Crew Members' Pay.

The equation on pay for other crew members takes cognisance of the compromise mentioned above when aeroplane speeds are increased markedly and it assumes the company could gain only one-half of the theoretical economy on crew pay as aeroplane speeds increased in the future.

The expression (Annual Pay at V_{bo}) indicates about the present average annual pay of second pilots and stewardesses at present average block speeds of 160 m.p.h. or $3,700 and $1,620, respectively. Flight engineers and cabin boys are assumed to receive $2,400 and $1,420 flat annual pay for present block speeds. The cockpit crew is assumed to work 850 flying hours and the cabin crew 900 flying hours annually.

In the expression $(1+V_b/160)/2$, 160 represents present block speed in m.p.h. on the United Air Lines system and the formula is designed to allow one-half of the theoretical economy provided by increased aeroplane speed.

Crew Expense.

Cockpit Crew.

$$C_m=(\text{per mile cost})\ (\text{crew members})/L=0.00225\ (\text{crew members})/L \qquad (10)$$

Cabin Crew.

$$C_m=(\text{per mile cost})\ (\text{crew members})/L=0.00344\ (\text{crew members})/L \qquad (11)$$

This cost includes allowances to the aeroplane crew for hotel bills and meals when away from point of domicile, moving expenses involving transfers of personnel, and rent, bedding and linen, etc., of stewardess apartments. The 0.00225 and 0.00344 are in terms of dollars per mile taken from actual operating experience.

Aeroplane Public Liability and Property Damage Insurance Cost.

$$C_m=\text{rate per mile}/L=0.0013/L \qquad (12)$$

This type of insurance is quoted by insurance underwriters on a per mile flown basis and it is known that such insurance coverage might be purchased at rates from $0.0011 to $0.0014 per mile flown. An average rate of $0.0013 is used above.

Interest on Investment.

$$C_m=(\text{Average investment}/C_t)\ (\text{Interest rate})\ C_t/UV_bL$$
$$=(0.7)\ (0.04)\ C_t/UV_bL \qquad (13)$$

Average investment is considered to be 0.7 of money originally invested, and interest lost due to money invested is assumed at the rate of 4 per cent.

AEROPLANE ACCIDENT INSURANCE (CRASH, FIRE, WIND) COST.

$$C_m = (\text{Insured value}/C_t)\,[(\text{Rate per dollar valuation})\,C_t/UV_bL]$$
$$= (0.9)\,(0.08)\,C_t/UV_bL \quad . \quad . \quad . \quad . \quad (14)$$

During the past four years an approximate check reveals that major domestic transport operators' losses from crash have amounted to less than 4 per cent. of original fleet values. It is known that insurance underwriters have quoted in the recent past crash insurance rates ranging from 5 per cent. to $7\frac{1}{2}$ per cent. of insured values according to the individual company's accident records.

Crash insurance purchased in the open market for expensive four-engined aircraft would likely to be high at first because of the tremendous risk tied up in a single aeroplane and therefore the desire on the part of the insurance company to accommodate a fund of money quickly from which to meet contingencies.

Fire and extended coverage insurance can be purchased for large transport aeroplanes of to-day at prices ranging from \$0.0160 and \$0.0230 per dollar of insured value per year. For purposes of this paper, the figure \$0.08 for all aeroplane accident insurance has been used.

Insured value may not always be equivalent to original cost depending on the state of obsolescence of the aeroplane and whether or not it would be replaced if destroyed. The preceding equation assumes an average insured value over the life of the aeroplane of 0.9 of original cost.

COSTS THAT CHANGE WITH PASSENGER VOLUME.

The operating costs that move with volume of passengers are not considered a part of significant cost. Although most of these costs are generally considered direct operating in nature they are dependent primarily on the number of passengers aboard and will remain fairly constant per passenger regardless of equipment operated.

The following list sets forth those cost classifications considered to be closely associated with passenger volume:—

(1) Telephone and telegraph, reservations, (2) passenger liability insurance, (3) food and food supplies, (4) commissions paid to agents for ticket sales, (5) cost of passenger ticket stock and other passenger supplies.

Experience indicates the above classifications will total about \$0.005 per mile per pay passenger aboard an aeroplane. This unit figure is more applicable to a trans-continental service and the figure for feeder line service will undoubtedly be smaller. A simple equation to obtain this cost is:—

Passenger Service Cost in Dollars per Mile = 0.005 (Number Passengers Aboard) (15)

AEROPLANE UTILISATION.

GENERAL.

Utilisation per year per aeroplane represented in the cost equations of this study by "U" has such an important bearing on total significant cost that a short section of this paper devoted to its treatment is felt justified.

Aeroplane utilisation is determined by the following factors:—

(1) The type of work the aeroplane has to do.
  (*a*) Coast to coast sleeper service.
  (*b*) Short or medium haul frequency service.
  (*c*) Local, terminal or feeder service.
(2) Amount of error entering into projection of business prior to fleet purchase.
(3) Seasonal fluctuation of scheduled mileage.
(4) Time lost because of overhaul, unexpected contingencies, and protection of service with spare aeroplanes.

Before an aeroplane or group of aeroplanes is purchased by an air transport company, the work that the aeroplane will have to do, the amount of business

expected, the peak period requirements to satisfy the expected business demand are carefully worked out. The specific work the fleet will have to do is the greatest single factor in predetermining the general bracket of utilisation within which the aeroplanes will fall. Errors in judgment as to the amount of passenger business that might be available prior to fleet purchase and/or seasonal schedule fluctuation will affect utilisation one way or another within the "job bracket." Usually a major operator will try to provide cargo space and seats to satisfy in excess of 95 per cent. of business offering over the peak summer period lasting from June through October. If the nature of the operation is highly seasonal, there are likely to be aeroplanes not utilised to a great extent during the winter months.

It is quite obvious that the aeroplane used in trans-continental sleeper service will always have the highest utilisation factor. The aeroplane used in feeder or local service will show in general the lowest utilisation and the aeroplane used to provide frequency of service between thickly populated areas such as Boston-New York, New York-Chicago will attain an in-between utilisation goal.

This Study.

If it became practicable or possible to use a fleet of aeroplanes of a given type in trans-continental service alone, each operating coast-to-coast daily, an overall utilisation in excess of 810,000 miles per year per aeroplane might be consummated. This is over 4,000 hours per year at a block speed of 200 m.p.h. Unfortunately this probably would not be the case if a fleet of aeroplanes of the general type being compared in this study were operated by a trans-continental carrier. Such a fleet would probably divide most of its flight time in trans-continental and local Chicago-New York or other similar local service.

For the purpose of this study the utilisation has been planned on a mileage basis with the assumption that the aeroplanes investigated would be operated trans-continentally three round trips per day as well as New York and Chicago with two round trips daily in addition to the trans-continental operation. Immediately below is Table I setting forth the mileage calculations on an annual basis and aeroplanes utilised for this service.

Table I.

Mileage Calculations on an Annual Basis and Aeroplanes Utilised.

Schedules.	Miles.	Aeroplanes.
Three round trips coast-to-coast	5,694,000	6
Two round trips Chicago-New York ...	1,095,000	2
Reserve aeroplane	—	1
	6,789,000*	9

The equation for utilisation as used in eqs. (3), (13) and (14) becomes

$$U = 6{,}789{,}000/9 \quad V_b = (7.54/V_b) \times 10^5 \quad . \quad . \quad . \quad (16)$$

Table 1 makes no allowance for curtailment of scheduled service in the winter. Also a minimum of spare equipment is planned; there is virtually none for schedule protection, and it is considered that most overhaul and repair as well as engine change work will be accomplished at tide water terminals during the daytime between trans-continental sleeper schedule arrivals and departures. Due to equipment size and schedule frequency planned, no aeroplanes are provided for extra sections. In short, the utilisation of mileage as set up in Table I approaches the ideal for present-day trans-continental operators.

* Ferry and test mileage assumed to offset miles cancelled.

Utilisation Largely a Function of Trip Length.

For most schedule set-ups, as the block speed of an aeroplane increases, its hourly utilisation is affected inversely. This paradox is best illustrated by trans-continental sleeper schedules. An aeroplane barely able to make a coast-to-coast trip with reasonable time at its termini for service before the return trip will attain higher utilisation than the aeroplane which is capable of flying the same route in less than half the twenty-four-hour period. After reaching tide water and after an adequate service period, neither aeroplane could be counted on for additional flight service without jeopardising the return trans-continental departure time. This would be especially true if overhaul work were performed during the day. Utilisation is limited further by trip length as the length of the trip is shortened. This situation will prevail generally until block speeds of aeroplanes are doubled compared to present speeds.

Speed Requirements.

If additional speed is not required for service of local nature, the maximum speed necessary in domestic operation might be determined by a block speed fast enough to fly an overnight coast-to-coast eastbound schedule. If cargo and passengers could leave the west coast at the close of a business day, the passengers go to bed on the aeroplane and arrive at their destination on the Atlantic seaboard at the start of the next business day, there really would be no occasion for greater speed.

Present aeroplanes accomplish this goal on westbound trips because the time belt changes are in the aeroplanes favour. Transport aeroplanes now leave the east coast at about 5.00 p.m. Eastern Standard Time and arrive on the west coast about 9.20 a.m. Pacific Coast Time. Eastbound, of course, the opposite is true, and the speed of the aeroplane must overcome time-belt changes if an overnight flight is to be accomplished. This time-belt handicap on eastbound flights is partially overcome by prevailing winds which blow from west to east and usually help an aeroplane flying in this direction.

If a trans-continental overnight service is assumed eastbound with a 15 m.p.h. tail wind, the pertinent factors regarding such a schedule are set forth in Table II below.

Table II.

Factors for Eastbound Trans-continental Overnight Service.

		Stops.			Cruising Speed.
Leave.	Arrive.	No.	Ground Time.	V_b	Still Air.
6.00 p.	8.00 a.	2	30 min.	260 m.p.h.	273 m.p.h.
6.00 p.	8.00 a.	3	20 min.	260 m.p.h.	281 m.p.h.

The above schedule approaches an ideal for eastbound service and an aeroplane with a block speed 30 m.p.h. slower might still be satisfactory on an eastbound over-night flight. Westbound, the same aeroplane as illustrated in Table II might leave the east coast late enough to allow the passenger to have eight o'clock dinner at home and arrive at the airport to connect with a schedule due on the west coast at the beginning of the next business day.

Effect of Utilisation on Cost.

According to the cost equations set forth in this study, aeroplane utilisation will affect the following significant costs: (1) Aeroplane depreciation, (2) aeroplane accident insurance, and (3) interest on investment.

Fig. 2 illustrates the profound influence of aeroplane utilisation on significant cost as outlined in this study.

It will be noted from Fig. 2 that direct costs per mile flown may be made to fluctuate as much as 8 cents between the limits of utilisation of 2,200 and 3,720 hours per annum. An aeroplane used entirely for short or medium haul frequency of service might well only be utilised 2,700 hours per year or less whereas, as previously explained, if the same aeroplane were engaged chiefly in trans-continental service, its utilisation might be 3,700 hours or more per year.

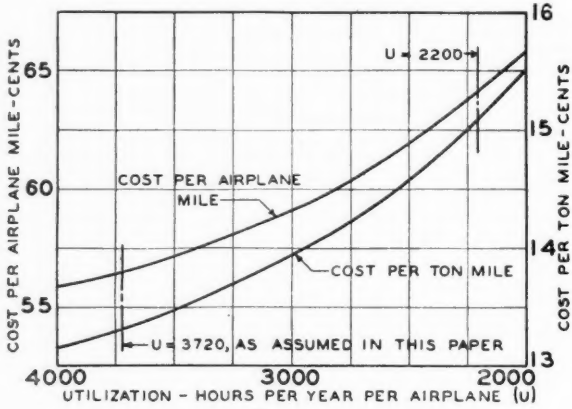


FIG. 2.

Significant costs as affected by utilisation for aeroplane later described as $f=35$ sq. ft. 600-mile range, block speed of 202 m.p.h.

OVERHEAD COSTS.

Total air transportation operating costs have been found to be divided into three general groups (two of which have already been explained) as follows: (1) Significant costs, (2) passenger volume costs, and (3) overhead costs.

There have been many theories expounded as to the allocation of overhead costs to direct operating costs. It is a perplexing problem because the allocations are affected by so many variables such as a utilisation of flying equipment, size of flying equipment as well as the difference in fundamental nature of a host of overhead cost classifications. The perplexity is also increased when the problem of allocation is considered for an air transport line which uses more than one type of flying equipment in its day-to-day operation. At best, it appears that the treatment of overhead will always be more arbitrary than the treatment of significant costs.

If a straight weight carrying allocation basis is used, then the more efficient aeroplane takes a cost penalty for its increased efficiency compared to the one with less efficient weight ratios.

Some operators maintain that overhead should be allocated on the basis of "ability to pay." With this system the aeroplane which is a passenger and cargo getter will bear the brunt of the overhead load, and the aeroplane less popular or one which is necessary to satisfy the minimum demand of public convenience and necessity perhaps, assumes the lesser overhead burden.

There is no question but that a sprinkling of large aeroplanes, such as described in this study, within a fleet of smaller aeroplanes will tend to increase such overhead costs as property taxes, certain ground insurance, ground passenger service personnel, hangar rents, certain ground depreciation, etc. Therefore, the larger aeroplane should bear a greater portion of overhead.

When the many cost classifications which as a group constitute the overhead load are examined, it is found that all are not a function of the same base. For example, the cost of ground flight personnel (dispatchers, meteorologists, radio operators, and clerks) might best be allocated on a schedule or per mile basis; passenger and cargo getting cost, including passenger agents and reservations personnel as well as promotional activity, might well be allocated on the basis of revenue load, or dollars of revenue.

It is reasonable to assume that hangar rentals, depreciation of ground servicing and housing facilities and fees for the use of landing areas are more closely associated with aeroplane weight than any of the aforementioned allocation bases. In other words, it would seem that the allocation of overhead should depend on a series of equations (as with significant costs) covering the several avenues of overhead spending, each equation being dependent upon the association with or function of the cost considered. It is not believed reasonable to assume that overhead is directly proportional to significant cost regardless of the type of flying equipment or service being considered.

Inasmuch as this paper has for its principal purpose the economic aspects of aeroplane performance, no attempt has been made to work out detailed equations for the distribution of overhead.

Part II.

Presentation of Aeroplane Characteristics in Terms of Significant Operating Cost.

It is the purpose of Part II of this paper to show, by applying the foregoing cost equations to a related series of aeroplanes, the effect on significant cost of varying cruising power available, cruising power required, aeroplane first cost, and trip length.

Block Speed.

Block speed is the only aeroplane performance characteristic appearing directly in the cost equations. It can be defined as the distance from terminal to terminal divided by the time from passenger station to passenger station. An accurate determination of block speed requires the computation of climb, level and descent distances and times as well as the arbitrary establishment of a terminal manœuvring and taxi time. For purposes of simplification in this study the following assumptions are made: (*a*) Flight altitude—14,000 feet; (*b*) terminal altitudes—sea level; (*c*) wind velocity—zero; (*d*) net time lost in climb and descent —0.06 hour; (*e*) taxi and manœuvring time—0.20 hour. In order to account for inaccuracies in flying, necessary deviations from true course and other contingencies, it is further assumed in the computation of block time that the distance is increased 2 per cent. Based on the above assumptions, the equation for block speed can be expressed as

$$V_b = D/\{(1.02\,D/V)+0.26\} \quad . \quad . \quad . \quad . \quad (17)$$

where V_b = block speed, m.p.h.

V = level flight speed at altitude, m.p.h.

D = trip length, miles.

Basic Aeroplanes.

The significant costs of a particular type of transport aeroplane are investigated. The type of aeroplane selected is a four-engine, low-wing monoplane sleeper having a supercharged cabin and passenger accommodations somewhat superior to aeroplanes now in service. The type closely approximates transport aeroplanes now under construction.

Three basic aeroplanes differing from each other only in the value selected for f (which is defined as the flat-plate area of unity drag coefficient equivalent to

minimum profile and parasite drag) are assumed. These basic aeroplanes are further assumed to have certain characteristics in common, as given in Table III.

TABLE III.

CHARACTERISTICS COMMON TO THE THREE BASIC AEROPLANES.

Wing area	1,430 sq. ft.
Aspect ratio	9·5
Span	116 ft.
Aeroplane "efficiency factor," e	0.87
Propeller efficiency, η	0.85
Maximum desired cruising speed at 14,000 ft.	225 m.p.h.
Gross weight	50,000 lbs.
Useful load	15,000 lbs.
Wing and nacelle weight	7,200 lbs.
Weight empty	35,000 lbs.
Crew weight (3 at 170 lbs. and 2 at 130 lbs.)	770 lbs.
Landing gear weight in per cent. of gross weight	7·5 per cent.
Engine and propeller weight in terms of cruising b.h.p.	2.90 lb./b.h.p.
Total take-off b.h.p. available	5,200 b.h.p.
Cruising specific fuel and oil consumption	0.46 lb./h.p. hr.
Number of day seats	0.40

The first of the basic aeroplanes is assumed to be designed according to present standards which results in f being equal to 35 sq. ft. The other two basic aeroplanes are assumed to be successively cleaner aerodynamically and are arbitrarily assigned values of $f=27.5$ and $f=20$. Aerodynamic efficiency is used in this paper to denote the degree of aerodynamic "cleanness." For purposes of convenience the basic aeroplanes are henceforth designated simply by their f values in sq. ft. All of the basic aeroplanes have the same take-off power loading and the same wing loading. Consequently their take-off and landing characteristics are almost identical inasmuch as f has little effect on either take-off or landing performance. However, the powers required computed for a level speed of 225 m.p.h. at 14,000 feet are 2,600, 2,150 and 1,730 b.h.p. for the f-35, f-27·5, and f-20 aeroplanes, respectively.

VARIATION OF CRUISING SPEED.

So far only one cruising speed has been determined for each aeroplane, but any cruising speed within reasonable limits can be obtained by varying the cruising power available. The simplest way to vary cruising power is to assume a specific engine and arbitrarily increase the amount of cruising power that is taken out of it. There is, of course, a limit to what can be done along this line without seriously impairing engine reliability. Existing engines appear to operate with good reliability up to 50 per cent. of take-off power, therefore this figure is adopted as the limit of cruising power of any specific engine.

In this study it is desired to investigate speeds higher than those obtainable by using 50 per cent. of the take-off power available in the basic aeroplanes. This necessitates the installation of more powerful engines which in turn increases the take-off power available. If more powerful and consequently heavier engines are installed either the useful load must be decreased or the gross weight increased. The latter alternative, which results in a constant useful load, is believed reasonable within the range of gross weights under consideration for the following reasons: (*a*) The increase in wing loading is more than offset by the decrease in power loading so that take-off and climb performance should not be impaired. (*b*) The increased wing loading will increase landing and

approach speeds slightly, but climb-out performance with the wing flaps set for the approach condition should be improved by the reduced power loading. The increased landing run is at least partially compensated for by the ability of the aeroplane to climb-out more rapidly in the event of an inaccurate approach to the landing area.

VARIATION OF WEIGHT.

If comparable structural integrity is to be obtained, the strength, and consequently the weight, of the wings, engine nacelles, fuselage and tail group must be varied with speed. The determination of the exact variation of structural weight

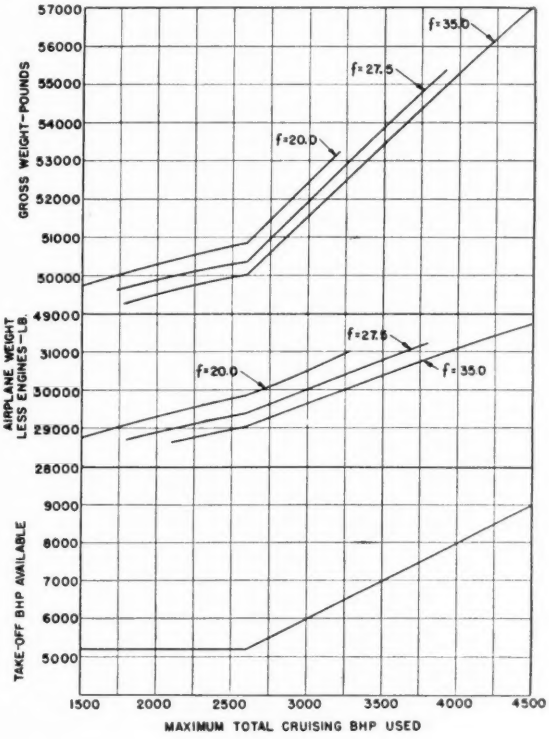


FIG. 3.

Gross weight, aeroplane weight less engines and take-off power available plotted against maximum total cruising power used in accordance with Eq. (19).

with speed is extremely complex, but can be approximated by making several simplifying assumptions, namely: (*a*) That the weight changes in the fuselage and tail group are small and can be neglected, (*b*) that the wing and nacelle weight varies directly with the maximum cruising speed; (*c*) that some arbitrary percentage (75 per cent. in this case) of the basic wing and nacelle weight is made up of actual structural material; and (*d*) that the maximum cruising speed in any particular instance is proportional to the cube root of the maximum cruising power selected. The maximum cruising power selected may be less than but never greater than 50 per cent. of the take-off power available. It is assumed that

cruising power for level flight or descent will be limited by placard or otherwise to that necessary to obtain the arbitrary maximum cruising speed selected in any instance.

The landing gear is the only variable weight item remaining. As mentioned in Table III it is assumed to constitute 7.5 per cent. of the gross weight.

Having made the above assumptions it is possible to set up the following approximate equation for variation of gross weight in terms of maximum cruising power bearing in mind that the structural limit speed (so called " never exceed " or " placard " speed) must be varied to suit the maximum cruising speed and power selected in any particular instance.

$$GW = GW_0 + (1 + A)\,[EB + D\,(W\,\{P^{1/3}/P_0^{1/3}\} - W)] \quad . \quad (18)$$

where GW = gross weight in lbs.

A = landing gear weight in per cent. of gross weight expressed as a decimal.

B = specific engine weight in lbs. per cruising b.h.p.

D = arbitrary ratio of structural to total wing weight.

W = basic aeroplane wing and nacelle weight in lbs.

P = total maximum cruising b.h.p.

E = (P − 50 per cent.) of the basic aeroplane take-off b.h.p.*

The subscript o denotes values pertaining to the basic aeroplane while no subscript denotes values pertaining to the revised aeroplane.

Substituting the values previously assumed eq. 18 becomes

$$GW = 50{,}000 + 1.075\,[2.9\,(P - 2{,}600) + 0.75\,(7{,}200\,\{P^{1/3}/P_0^{1/3}\} - 7{,}200)] \quad (19)$$

where P_0 = 2,600 for *f*-35 aeroplane.

P_0 = 2,150 for *f*-27.5 aeroplane.

P_0 = 1,730 for *f*-20 aeroplane.

The useful load is assumed to be constant and therefore if the engine weight is assumed to be a function of take-off or cruising power the weight of the aeroplane less engines can easily be determined.

Gross weight, aeroplane weight less engines, and take-off power are plotted against maximum total cruising power used in Fig. 3. It should be noted that no additional take-off power has been provided to compensate for additional wing, nacelle and landing gear weight. However, the effect of this additional weight on take-off and landing performance is not great and is neglected in the interest of simplicity.

Cruising Power Required.

The cruising b.h.p. required at 14,000 feet altitude is computed for each of the aeroplanes at various gross weights by use of the following equation :—

$$\text{b.h.p. required} = (\rho f V^3/1{,}100 + 2\,W^2/500\,\rho\pi e b^2 V)/\eta \quad . \quad (20)$$

where ρ = atmospheric density in slugs per cubic foot.

f = profile and parasite equivalent flat plate area in sq. ft.

V = velocity in ft. per sec.

W = gross weight in lb.

e = aeroplane efficiency factor.

b = span.

η = propeller efficiency.

Fuel and Oil Reserves.

Before the pay load for any flight can be determined it is necessary to establish what reserve fuel and oil is to be carried. Present government requirements state that sufficient fuel must be carried to keep the aeroplane aloft for 45 minutes after reaching its destination. However, the destination must be the most remote alternate airport set forth in the flight plan for the particular trip. For the purposes of this study, no time reserve is assumed but each aeroplane is

* If E is negative it must be assumed equal to zero in order to maintain take-off performance.

assumed to have enough fuel on board to fly 300 miles at cruising power after reaching its destination. Oil necessary for the trip plus 300 miles, as well as an additional 20 gallons of oil per engine, is also assumed to be on board.

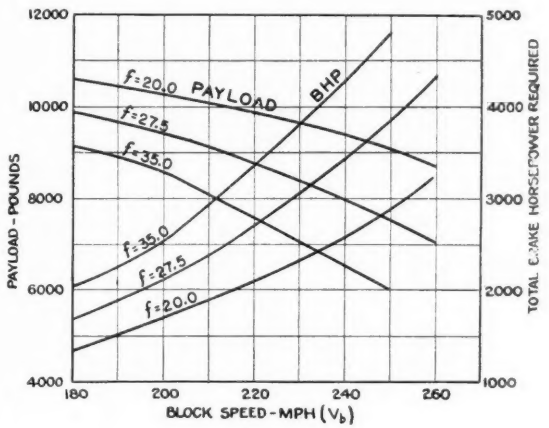


FIG. 4.

Pay load and total b.h.p. required for a trip length of 600 miles plotted against block speed.

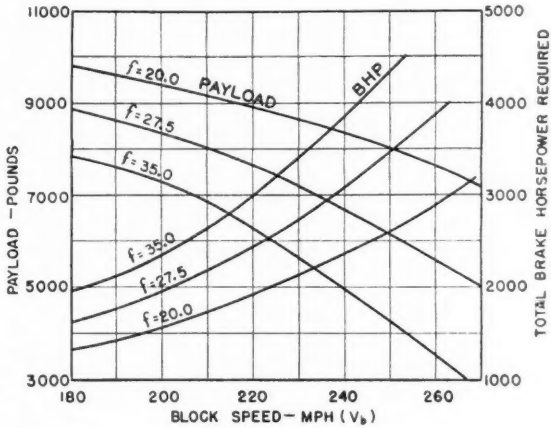


FIG. 5.

Pay load and total b.h.p. required for a trip length of 900 miles plotted against block speed.

PAY LOAD.

Relationships having been established between true speed and block speed, and between true speed, weight, and power, it is now possible to compute pay loads for trips of different lengths when operated at different block speeds. In computing block speeds the approximate average gross weight for the particular length trip being investigated is used. Figs. 4, 5, and 6 show pay load plotted

against block speed for the three assumed values of f and for trip lengths of 600, 900, and 1,200 miles. On the same figure the total cruising b.h.p. required is plotted against block speed. These curves show quantitatively the effect of block speed and aerodynamic efficiency on pay load. The three curves when considered together show the effect of trip length on pay load. They form the basis for the presentation of aeroplane performance in terms of significant cost.

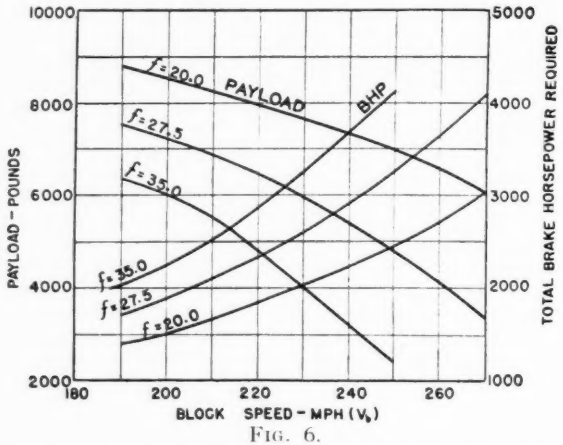


FIG. 6.

Pay load and total b.h.p. required for a trip length of 1,200 miles plotted against block speed.

WEIGHT AND COST RELATIONSHIPS.

Before significant costs can be determined certain cost and weight relationships must be established. The symbols defined in Part I are used. Current aeroplanes of the general type of the f-35 aeroplane being considered cost approximately \$11.00 per pound of aeroplane weight less engines but including propellers. Current engines weigh approximately 2.3 lbs. per maximum cruising b.h.p. for reasonable reliability, and cost approximately \$9.40 per pound or \$21.60 per cruising b.h.p. The above relationships can be written as follows:—

$$C_a = 11\ W_a \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (21)$$

$$W_e = 2.3\ P/4 = 0.575\ P \quad . \quad . \quad . \quad . \quad . \quad (22)$$

$$C_e = 21.60\ P/4 = 5.40\ P \quad . \quad . \quad . \quad . \quad . \quad (23)$$

$$C_t = C_a + NC_e = 11\ W_a + 5.4\ PN \quad . \quad . \quad . \quad (24)$$

It should be borne in mind that the symbol P represents the total cruising b.h.p., which in this study is the sum of the cruising b.h.p. of four engines, and that the symbols W_e and C_e represent the weight and cost, respectively, of one engine.

SIGNIFICANT COSTS.

Relationships have now been established so that all variables appearing in the significant cost equations of Part I can be determined for any block speed selected. For comparing the effect of aerodynamic efficiency, cruising power, and range on significant cost, only the total cost is necessary. However, Figs. 7, 8, and 9 are shown for the three values of f and for a 900-mile trip length to illustrate the relative importance of the individual cost factors. Factors that are more or less related are combined in the interest of simplicity.

The most striking feature of Figs. 7, 8, and 9 is the rapidity with which significant fuel cost increases as block speed increases in the case of the *f*-35 aeroplane, and the rapid reduction in the effect of significant fuel cost as aerodynamic efficiency improves. Significant cost is influenced not only by the cost of additional fuel consumed as block speed is increased, but also by the reduction of pay load necessitated by the greater fuel requirements. As the aerodynamic efficiency improves, the fuel on board becomes a smaller and smaller percentage of the useful load.

It will be noted that pay load appears in the denominator of all significant cost equations. For any given aeroplane the useful load is essentially fixed. Consequently pay load is almost entirely a function of the amount of fuel on board and for that reason all significant costs are affected indirectly by fuel requirements.

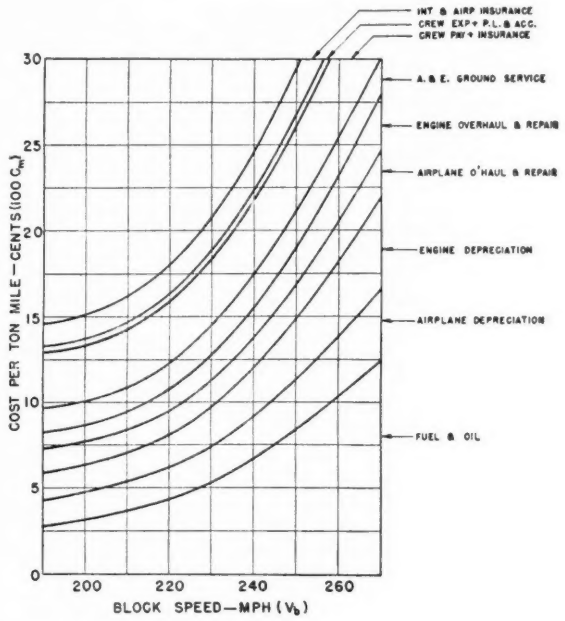


FIG. 7.

Significant cost factors vs. block speed for 900-mile trip length and f=35 sq. ft.

SPECIFIC FUEL CONSUMPTION.

Although not studied quantitatively in this paper it is obvious that reduction of specific fuel consumption has an effect on cost somewhat similar to but much less important than improvement in aerodynamic efficiency. For instance, if specific fuel consumption were reduced approximately 33 per cent. (from 0.45 lb. to 0.30 lb. per b.h.p. hr.) on a 900-mile trip operated at a block speed of 209 m.p.h. with the *f*-35 aeroplane the actual fuel consumed would be the same as that consumed by the *f*-20 aeroplane when operated at the same speed and for the same distance with a specific fuel consumption of 0.45. However, if the block speed were increased, the specific fuel consumption of the *f*-35 aeroplane would have to decrease very rapidly to maintain the above relationship. Further-

more, increases in block speed above 209 m.p.h. (for a 900-mile trip length) require more and more powerful engines in the f-35 aeroplane whereas more powerful engines are not required in the f-20 aeroplane until a block speed of 250 m.p.h. (for a 900-mile trip length) is reached. If constant engine specific weight is assumed, more powerful engines affect all of the significant cost factors

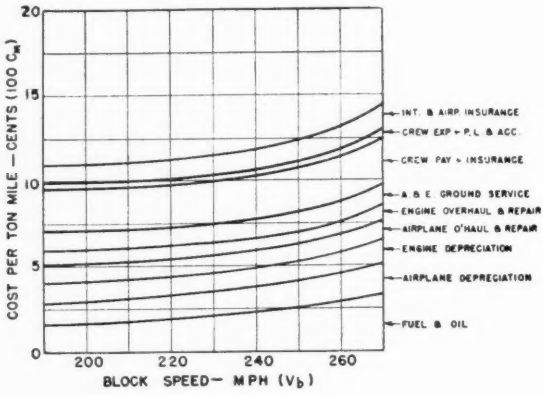


FIG. 8.

Significant cost factors vs. block speed for 900-mile trip length and $f=20$ sq. ft.

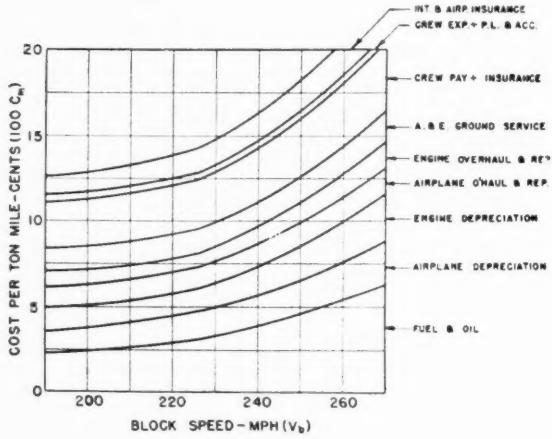


FIG. 9.

Significant cost factors vs. block speed for 900-mile trip length and $f=27.5$ sq. ft.

indirectly through reduction in pay load and affect some of them, such as engine overhaul, engine depreciation, interest on investment, and aeroplane insurance, directly. Therefore, while reduced specific fuel consumption cannot be overlooked as a means of reducing significant cost it is of secondary importance when compared with improvement of aerodynamic efficiency.

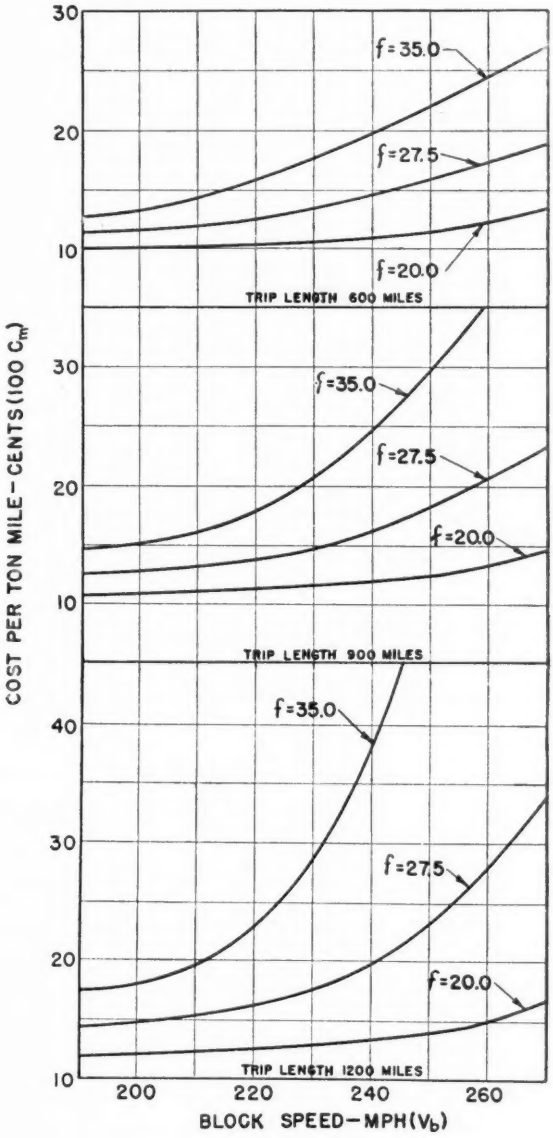


FIG. 10.

Significant costs vs. block speed for trip lengths of 600, 900, *and* 1,200 *miles.*

SIGNIFICANT COST COMPARISON.

Fig. 10 is plotted to show directly the effect on total significant cost of changing block speed and aerodynamic efficiency for three different trip lengths. This figure shows directly the great effect that aerodynamic efficiency has on significant cost as block speed and trip length increase. The 260 m.p.h. block speed (which assumed a 15 m.p.h. tail wind), established in Part I as approaching the maximum block speed required for trans-continental service, corresponds roughly to a 240 m.p.h. block speed in still air. Reference to Fig. 10 shows that if the trip lengths are 900 miles the significant cost for the *f*-35 aeroplane is nearly 25 cents per pay load ton-mile while the significant cost for the *f*-20 aeroplane is just under 12 cents or approximately half that of the *f*-35 aeroplane. Similar comparisons can be drawn for other block speeds and trip lengths.

AEROPLANE FIRST COST.

All of the previous data presented are arbitrarily based on the assumption that the first cost of all aeroplanes is $11.00 per pound of aeroplane weight less engines, because the rate of change of aeroplane first cost as aerodynamic efficiency increases is highly indeterminate. It is reasonable to assume, however, that this cost per pound will increase as aerodynamic efficiency increases. In order to show the effect of increasing aeroplane first cost on significant cost Fig. 11 is presented. In this figure significant cost is plotted against block speed for a trip length of 900 miles and for the *f*-35 aeroplane assuming the original aeroplane cost of $11.00 per pound. The same information is plotted for the *f*-20 aeroplane assuming the original aeroplane cost of $11.00 per pound and also assuming that this cost is increased successively to $27.50 per pound, that is, to 250 per cent. of the original value. It can be seen that even this absurdly high aeroplane cost is justified theoretically if block speeds above 160

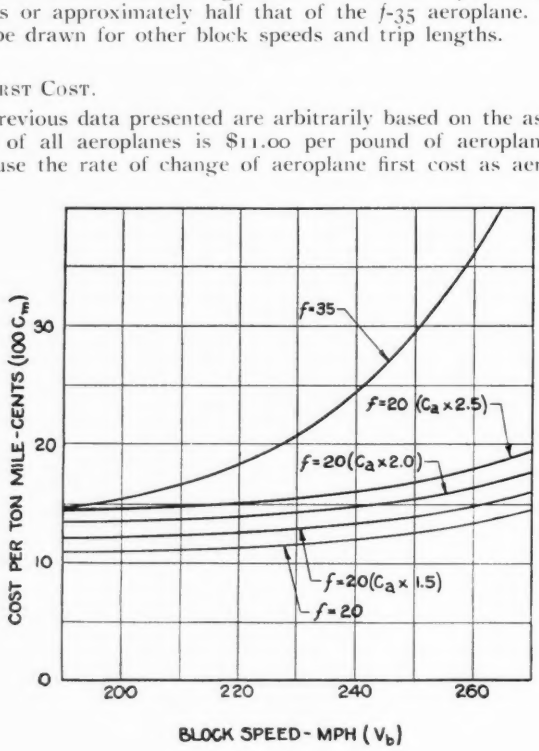


FIG. 11.

Significant cost vs. block speed for a 900-mile trip length and variable aeroplane first cost.

m.p.h. are desired. Of course a value of $f = 20$ for the type of aeroplane under consideration is not realisable in the present state of the art. The value of f for the cleanest aeroplane was intentionally made much lower than has been demonstrated on any existing transport aeroplane in order to emphasise the importance of aerodynamic efficiency and to show that increased aeroplane first cost is justified in order to obtain cleanness.

The above remarks about aeroplane first cost must not be interpreted too literally inasmuch as they present only the theoretical cost side of the picture. In Part III of this paper other factors which influence the over-all economy of a particular operation are set forth. The possible action of one or all of these factors would undoubtedly make the business risk of investment in aeroplanes of the type studied, which might cost $1,000,000 each, too great for consideration even though the increase in efficiency might be great. However, it does follow that relatively large increases in aeroplane first cost can be justified if they result in sufficient improvement in aerodynamic efficiency.

Trip Length.

The aeroplane designer has no control over trip length. The transport operator, however, must choose in many instances between the economy of shorter trips and the greater public appeal resulting from longer trips. Reference to Fig. 10 shows the relatively great effect of trip length on significant cost for the aeroplanes studied. The short trip is less efficient than the long trip in that a higher true speed is required to make good the same block speed. This is due to the fact that the fixed taxi time, manœuvring time, and net time lost in climb and descent remain constant and therefore represent a larger proportion of the total time on a short trip than on a long one. However, the increased fuel required much more than offsets this inefficiency on trips of reasonable length. Of course if trip lengths are shortened too much the total pay load capacity cannot be utilised in most instances because the number of seats is limited.

Obviously the cleaner the aeroplane the better it is on long trip operation because the fuel required for a given trip represents a smaller proportion of the useful load as the cleanness of the aeroplane increases.

Part III.

Economic Factors Not Associated with Design and Performance.

The purpose of Part III of this paper is to point out certain other economic factors of air transportation apart from those pertinent to aeroplane design and performance.

These outside economic considerations which have been operative during the brief history of air transportation are centred around such factors as:—

(1) Interior arrangement and passenger comfort.
(2) State of general public acceptance.
(3) Nature of the competition.
(4) General economic conditions.

The above enumerations may seem quite obvious but it is believed important that they be reviewed just briefly as they have assumed, during the past, the major rôle in the control of the economic destiny of the various individual air transport companies.

In consideration of factor (1), it might be said that the interior arrangement of an aeroplane providing berths and the almost simultaneous inauguration of trans-continental sleeper schedules provided real economic stimulus to the air transport industry. Although it is felt the present sleeper transport aeroplane used by domestic operators does not represent the best as an economic unit, its success as a business getter very definitely has demonstrated the value of proper considerations to interior arrangement and comfort, even at the expense of a

fundamentally less efficient aeroplane. In other words, the average layman probably does not make the finer engineering distinctions as to fundamental efficiency but his choice for air transportation is more likely to be made on the basis of those things that add most to his personal comfort and enjoyment.

In consideration of factor (2), the following is offered. Air transport history indicates that public acceptance of a new aeroplane model has been remarkable. It has been so remarkable in fact that an air transport organisation which has been able to precede the rest of the field with a new model has insured for itself with the new model immediate economic success. This leadership has continued as long as no new type of aeroplane is introduced in the field and as long as outside economic conditions have remained satisfactory. This single factor of competition has had a major bearing on the economic destiny of individual companies during the past five years, and is a factor that might well be considered by operators in purchasing new equipment as well as the factor of design efficiency.

Factor (3), or the state of general public acceptance of air transportation, is influenced profoundly by safety records. Air transport market studies indicate that fear and not fare has been the greatest single reason in the retardation of public acceptance of air travel. Lack of public acceptance due to reasons stated, therefore, has also been a major economic consideration in the air transport industry.

In considering factor (4), until recent years the air transportation industry was in such a stage of infancy that it seemed to create its own trend and was almost entirely immune to the effects of general economic conditions surrounding it. This fact is best illustrated by air transportation's steady growth during the depression years of 1930 through 1933. The number of passenger miles flown doubled during this period. Since about 1935, general business conditions have become a significant economic factor in the air transport picture. There is little doubt but that the industry did share in the benefits derived as a result of the upward trend of the industrial production index in 1936 and the fore part of 1937. Also no doubt the air transport passenger volume increase was retarded during the latter half of 1937 and first half of 1938, during which time the country as a whole suffered a recession in business compared to the previous year.

Conclusions.

It may be concluded that variation of aeroplane utilisation has a profound effect on significant operating cost; and that aeroplane utilisation in terms of flying time is fundamentally dependent on trip length, with a secondary dependence on such factors as seasonal schedule changes, block speed, etc. (as block speed increases, utilisation decreases).

It may further be concluded that material increases in aeroplane first cost can be justified if they result in a sufficiently great improvement of aerodynamic efficiency. The study indicates how rapidly significant operating cost increases on a modern conventional aeroplane as block speed increases when that increase in block speed is obtained only by the addition of power. This is true even if the gross weight is increased enough to offset the additional structural and engine weight. It is also shown that significant cost increases rapidly as trip length increases.

While only one general type of aeroplane is investigated in this study the method of attack, that is, the idea of expressing certain aeroplane characteristics in terms of significant cost, is applicable to any type of transport aeroplane. Further experience with the method will undoubtedly result in simplification and increased accuracy.

In consideration of Part III of this study, it may be concluded that economic factors apart from those pertinent to fundamental design and performance play a major rôle in the economic outcome of air transportation.

ABSTRACTS FROM THE SCIENTIFIC AND TECHNICAL PRESS.

Issued by the

Directorates of Scientific Research and Technical Development, Air Ministry.

(Prepared by R.T.P.)

No. 78. May, 1940.

Bell "Airacobra" P-39 Single-Seat, Single-Engine Pursuit Aircraft. (R. J. Woods, Aviation, Vol. 39, No. 3, March, 1940, pp. 40-1 and 104.) (78/1 U.S.A.)

The design of this machine is completely novel. The engine is installed near the middle of the fuselage behind the pilot and an extension shaft is used to drive the propeller. This arrangement not only permits optimum nose shape for low drag, but the location of the heavy weight of the engine near the centre of gravity of the aeroplane makes for economy in structural weight and reduces the polar moment of inertia about the centre of gravity, thereby giving maximum manœuvrability. The engine is an Allison Vee 12-cylinder liquid-cooled. All three elements of the tricycle landing gear are mechanically retractable. Armament consists of a 37 mm. cannon firing explosive shells and four machine guns for synchronised firing through the propeller disc. External surfaces of the machine have been specially treated to reduce skin friction drag to a minimum. The machine is described in detail. Manufacturers' specifications and performances are :—

Wing span	34 ft.
Overall length	29 ft. 9 in.
Overall height	9 ft. 3 in.
Wing area	213 sq. ft.
Wing loading	28.3 lb./sq. ft.
Power loading	5.3 lb./b.h.p.
Empty weight, approx.	5,000 lb.
Useful load, approx.	1,550 lb.
Gross weight, approx.	6,000 lb.
Maximum speed, around	400 m.p.h.
Cruising speed, approx.	325 m.p.h.
Service ceiling, above	36,000 ft.

Labour in Aircraft Production. (Aeroplane, Vol. 58, No. 1506, 5/4/40, pp. 481-2.) (78/2 Great Britain.)

It is estimated that to maintain an air force at a total permanent strength of 26,000 aeroplanes, necessitating 117,000 aircraft and 221,000 engine replacements per annum, the total labour force required will be approximately 2,400,000

people. With an additional number of, say, 6,500 for maintenance repair and overhaul, and labour in auxiliary industries, the total becomes approximately 3,600,000 workers in the direct and indirect labour forces required to establish and maintain an air force of this size. Enlargement of available man power can be achieved by the following measures:—

1. Longer working hours;
2. Female labour;
3. Transfer from non-essential occupations;
4. Utilisation of the unemployed.

In Germany, at present, 49 per cent. of potential female labour is occupied, in Britain only 34 per cent., leaving 66 per cent. still available. Non-essential occupations in Britain also occupy some 3,000,000 persons. The available margin in Germany in similar trades is not so great, and production of ersatz materials further reduces Germany's disposable margin of man-power.

New Italian Military Aircraft. (Les Ailes, No. 977, 18/4/40, p. 4, and Le Vie dell'Aria, Vol. 13, No. 13, 28/3/40, p. 12.) (78/3 Italy.)

The following table gives some particulars of new fighter aircraft:—

	Caproni Vizzola F.5	Aeronautica Umbra T.18	Reggiane Re.2000.
Span (m.)	11.29	11.50	11.0
Length (m.)	7.90	8.76	7.55
Height (m.)	3.0	2.88	2.28
Wing area (m.²)...	17.4	19.0	20.4
H.p.	840	1,000	1,000
Supercharged height (m.) ...	3,800	4,100	4,000
Total weight (kg.)	2,270	—	2,050
Useful load (kg.)	420	—	—
Min. speed (km./h.)	115	—	117
Landing run (m.)	200	—	—
Time of climb to 6,000 m. (min.)	6.0	—	6.0

All these aircraft are low wing monoplanes with radial engines and are fitted with retractable undercarriages. The F.5 has wooden wings, steel tube fuselage and dural tail. The engine is Fiat A-74 RC. 38 with a Fiat-Hamilton constant speed propeller. The undercarriage retracts inwards towards the fuselage.

The F.5 is characterised by a very large strength coefficient (> 16) and has a very high rate of climb (less than 6 min. for 6,000 m.). It is stated to be very manœuvrable in spite of its high speed.

The T. 18 bears some resemblance to the Seversky fighter. The Aeronautica Umbra factories are situated at Foligno and belong to the Macchi Group (designer is F. Trojarri). The engine is Fiat A-80 RC. 41 with Fiat-Hamilton constant speed propeller. The construction is entirely metallic (dural and steel). The undercart retracts towards the wing roots.

A fuselage of elliptic shape is adopted both for the F. 5 and T. 18 and considerable attention is paid to the fairing of the rear end of the roof of the pilot's cockpit into the top of the fuselage.

The Re. 2,000 is a dural shell structure, both for the wings and the fuselage. A Piaggio XI RC. 40 engine is fitted together with a variable pitch propeller. In spite of its high speed, the manœuvrability is stated to be excellent.

No further details have been released concerning these three fighters. (Top speed of F.5 is rumoured to be of the order of 510 km./h.). Nothing is known about the armament.

Apart from these three fighters, attention must be called to a new three-engined bomber Cant Z 1,007 bis, which is constructed entirely of wood (shell structure)

and in order to increase the fineness ratio, the two pilots are seated behind each other. The following data have been released for publication:—

Span—24.80 m.
Length—18.35 m.
Height—5.22 m.
Useful load—4,200 kg.
Minimum speed—135 km./h.
Climb to 4,000 m.—11 minutes.

The bomber is stated to be heavily armed (both offensively and defensively) and have a large radius of action (designer, Zappata).

The Stabilisation of an Aerial Bomb. (C. Cremona, L'Aerotechica, Vol. 20, No. 1, Jan., 1940, pp. 11-19.) (78/4 Italy.)

In order to obtain high terminal speeds and therefore maximum penetrations, the bomb must be of streamline shape. As is well known, such a shape is unstable at small incidence. This instability can be reduced, but never cured by a forward shift of the C.G. As in the corresponding case of the airship, stability can, however, be ensured by the provision of a suitable tail surface. The dimensions of such a surface are determined from wind tunnel experiments on the lift and moment coefficients of the tail-less bomb at various angles of incidence. The lift of the tail surface should be responsible for the major part of the restoring couple and this entails the use of high aspect ratios. Unfortunately, questions of stowage limit this factor and hence small oscillations of the bomb during its trajectory cannot be avoided. The motion in this case can be studied by the same method as is applied to the corresponding case of the dirigible, and the author hopes to refer to this problem in greater detail in a subsequent paper.

Germany and Roumanian Petroleum. (C. Berthelot, La Science et la Vie, No. 275, May, 1940, pp. 523-7.) (78/5 France.)

Roumanian production of petroleum increased to 6.6 million tons in 1938. Normally the supply of Roumanian petroleum products to the Reich is about 1.5-1.8 million tons per annum, mainly petrol (more than 1 million tons) and fuel oil. The greater part of this supply has always been transported by sea, but now has to travel by the Danube and by railway. Due to lack of tank wagons and tankers, and to railway difficulties, Germany has probably not received more than 500,000 tons of petroleum during the first six months of the war—barely two-thirds of peace time imports. During January, 1940, transport on the Danube was stopped by ice, and it is estimated that during January and February no more than 30,000 tons of Roumanian petrol reached Germany. Any large spring offensive by Germany is likely to lead to shortage of petrol supplies. The war reserves probably amount to 3-4 million tons of petrol, but from experience of the Polish war this would probably suffice for only 3-4 months of operations. In the present state of affairs all that Germany can hope, now that the Danube is the only route, is that its annual imports will increase to 1.5 million tons. In expert opinion this appears impossible.

Captive Balloons and Aerial Barrages. (W. Kirchner, Berlin, Publisher, E. S. Mittler and Sohn, 1939, 100 pp.) (78/6 Germany.)

CONTENTS.

A. CAPTIVE BALLOONS.

Captive balloon companies at the outbreak of the World War (1914), their organisation, strength and equipment; activities during the war and subsequent development. Methods of balloon observation; observation of transport behind the enemy front, observation during enemy attack, firing by the aid of balloon

observation. The World War from the enemy side. Modern balloon observation companies.

B. Aerial Barrages.

Historical survey. Modern equipment—balloons, cables, winches, holding mechanism. Protected targets—targets of large area and point targets. Attack and defence, and the effect of aerial barrages on the attacker. Newest war experiences in Germany and abroad.

Bibliography.

The Armament of Enemy Aircraft. (J. Beseler, Luftwissen, Vol. 7, No. 3, March, 1940, pp. 46-53.) (78/7 Germany.)

The armament of the following machines is briefly discussed:—

British.
Armstrong-Whitworth " Whitley."
Bristol " Blenheim."
Vickers " Wellington."

French.
Amiot 143.
Leo 45.
Potez 63.
Morane 406.
Curtiss P. 36 (supplied by the U.S.A.).

The following guns are described in some detail:—

British.
Browning Mark II.
Vickers M.I.

French.
Aviation 34.
Hispano-Suiza Cannon, Mark 9.
,, ,, Mark 404.

The captured material had been manufactured over the period 1935-40 and the lines of development are clearly indicated. The Lockheed Hudson (supplied by the U.S.A.) was fitted with British guns, whilst the P. 36 (also bought in the U.S.A.) and utilised by the French Air Force was fitted with the Belgian Browning gun, type F.N. 1938.

Very few critical comments are given.

(1) The view from the rear turret of the " Whitley " is to some extent spoilt by the curvature of the plexi glass and access to the turret is difficult, the passage way being very restricted.

(2) The view from the turrets of the " Wellington " is not very good and the space is very cramped if the gunner wears altitude clothing.

(3) The French armament (Aviation 34 and Hispano Mark 9 and 404) appears to be of more modern conception than the British. This applies especially to the gun mountings.

(4) Special reference is made to the " splinter " ammunition used on British aircraft. The bullet has a core of very brittle lead and the hollow nose is filled with light alloy for about one quarter of the length. At normal impact, the nose generally breaks off, but on account of the rear position of the C.G., the bullet has little stability and tends to lateral impact.

The author devotes considerable space to a discussion on the sighting angles available in the various turrets and the time taken by the hydraulic mechanism to cover the full range.

Review of Researches on Centrifugal Pumps Carried Out at the Technical High School, Brunswick. (C. Pfleiderer, Forschung, Vol. 2, No. 1, Jan.-Feb., 1940, pp. 43-44.) (78/8 Germany.)

The following are some of the main points covered:—

(1) Effect of blade number on performance.

(2) Losses due to flow reversal (rotor diffuser).

(3) Instability of operation.

(4) Predetermination of pump characteristics from blade shape.

Experiments were also carried out with water jet air pumps. Of special interest is a comparison between the methods of calculation employed respectively for steam and hydraulic turbines. It appears that such methods exhibit in some respect fundamental differences which are not justifiable on the ground of the physical differences in the working media. For example, the opinion is still widely held by steam turbine designers that the lines of flow behind an aexial guide channel are straight, and that therefore the pressure along the trailing edge is constant. In the corresponding hydraulic case of the Kaplan turbine the flow lines are assumed to have a constant velocity moment, and it appears that similar consideration should also apply to the steam case. If this is correct, blade angles as currently used require modification. This matter is being investigated by temperature and pressure measurement in the last stage of an axial flow steam turbine.

Aerodynamic Investigations of Hydraulic Machinery. (W. Spannhake, Forschung, Vol. 2, No. 1, Jan.-Feb., 1940, p. 45.) (78/9 Germany.)

Reference is made to experiments carried out by the Swiss firm of Escher Wyss on a model water turbine utilising air instead of the normal working fluid. This has the advantage that pressure measurements on the rotating blade can be carried out much more easily and the regions of cavitation (*i.e.*, lowest pressure) determined with great accuracy. Moreover, by using a compressed air tunnel it is possible to approximate to full-scale Reynolds numbers.

Conversely, experimental results obtained with incompressible fluids can, in many cases, be utilised in predicting the corresponding performance with air or steam, provided the laws of similarity are suitably extended. Modern aerodynamic theory has thus made it possible to choose the experimental conditions so that the required results are obtained in the simplest and most accurate manner.

The Influence of Reynolds Number at Large Mach Numbers. (A. Eula, L'Aerotecnica, Vol. 20, No. 1, January, 1940, pp. 20-29. Air Ministry Translation No. 1015.) (78/10 Italy.)

The experiments were carried out in the Guidonia supersonic wind tunnel on spheres and cylinders at Mach numbers of 1.85 and 2.15 respectively. The range of Reynolds number for the former was from 100,000 to 800,000 and in the latter from 50,000 to 200,000. This change of Re produced no measurable effect on the total resistance coefficient (wave + friction), at constant Mach number. Experiments are in progress for the separate measurement of the friction losses under these conditions.

The drag at these high velocities is in satisfactory agreement with that calculated from the pressure distribution and is almost entirely due to the forward high pressure region on the body (leading hemisphere). It is interesting to note that the total drag coefficient decreases slightly with increase in Mach number. If the effect of Re is truly negligible at these high velocities, one of the main objections to small scale supersonic wind tunnels disappears.

New Methods for the Calculation of Critical Velocity of Cantilever Wings Subjected to a Special Form of Elastic Instability. (T. Viola, L'Aerotecnica, Vol. 20, No. 3, March, 1940, pp. 191-204.) (78/11 Italy.)

A peculiar form of elastic instability may arise in cantilever wings due to the superposition of flexural and torsional instability. This problem has been treated analytically by Minelli and resolves itself into the determination of the first positive characteristic value of a certain system of ordinary, linear, homogeneous differential equations containing two unknown functions and satisfying certain limiting conditions. The author illustrates the method of solution of such problems, both analytically and numerically. The results show that, as could have been foreseen a shift of the elastic axis towards the rear increases the tendency of this peculiar instability to arise and hence reduces the critical velocity.

Application of High Lift Devices to Aeroplanes Designed Primarily for High Cruising Speeds. (R. M. Rogallo, J. Aeron. Sci., Vol. 7, No. 5, March, 1940, pp. 185-188.) (78/12 U.S.A.)

In horizontal flight, the weight W supported and the thrust T are respectively given by the equations

$$W = \tfrac{1}{2}\rho V^2 C_L S$$
$$T = \tfrac{1}{2}\rho V^2 C_D S$$

where C_L and C_D are the lift and drag coefficients of the aircraft and S is the wing area.

For a given W and S, the thrust h.p.

$$= C\rho^{-\frac{1}{2}}(C_D/C_L) \times (1/C_L^{\frac{1}{2}})$$

where C is a constant. At constant altitude, the thrust h.p. thus becomes a minimum at a certain C_L for which the product $(C_D/C_L) \times (1/C_L^{\frac{1}{2}})$ is a minimum. In the case of a normal wing, this minimum occurs at $C_L = 1.2$ app., the thrust h.p. being then about 92 per cent. of the cruising thrust h.p. ($C_L = 0.84$). By means of high lift devices, especially slotted flaps of the venetian blind type, C_L corresponding to minimum thrust h.p. can be raised as high as 2, the thrust h.p. under these conditions being only 75 per cent. of the cruising h.p. at $C_L = 0.84$. This improvement is made possible by the fact that high lift devices of this kind do not seriously increase the (C_D/C_L) ratio of the complete aircraft and the thrust h.p. thus varies app. inversely as the square root of the possible lift coefficient.

In the case of the conventional split flap, the increase in drag is such that the possible saving in minimum thrust h.p. is very much less. The reduction in minimum thrust h.p. required has a beneficial effect on the rate of climb and on the ceiling of the aircraft. In the case of complete engine failure, although the gliding range is generally not increased, the sinking speed and the landing speed are both reduced by a suitable high lift device.

In the case of multi-engined aircraft, with one engine dead, the venetian blind flap will produce a considerable reduction in engine power required. Thus, if the cruising power ratio is 0.75, the failure of one engine on a twin engine machine would entail overloading the remaining engine 50 per cent. if horizontal flight is maintained at the same C_L. At optimum C_L (standard wing) this is reduced to 38 per cent. and with a venetian blind flap the necessary overload is only 13 per cent. If the engine failure occurred at 8,000 feet, the overload is reduced to zero if the horizontal flight is continued at ground level (thrust h.p. varying inversely as the square root of the density).

Two Formulas for Take-Off Distance. (E. Lesher, J. Aeron. Sci., Vol. 7, No. 5, March, 1940, pp. 209-11.) (78/13 U.S.A.)

Two formulas for take-off distance, which are based on a previous paper by Hartmann (N.A.C.A. Tech. Note No. 557), are developed. The first formula takes into account all the important factors affecting take-off distance, and may

usually be trusted to give results in error by no more than 2 per cent. The second formula is a simplification of the first, and will usually give results accurate to within 5 per cent. Both formulas permit comparatively rapid solutions.

Wing Loading and its Effect on the Design of Transport Aeroplanes (concluded). (Inter. Avia., No. 706, 16/4/40, pp. 1-4.) (78/14 U.S.A.)

The final instalment of this article deals mainly with the effect of icing and according to the opinion of many pilots this effect becomes relatively more important at high wing loading. This conclusion is, however, in error. The larger wing picks up more ice on account of its increased surface and the lower speed increases the time during which the flight may be subjected to icing dangers.

The effect of ice is to reduce the maximum lift coefficient by about 30 per cent. and increase the cruising drag by 50 per cent. Most important, however, is the fact that the angle of stall is progressively reduced and the pilot has no means of telling how close he is to critical conditions.

Present day mechanical de-icers do not extend beyond 5 per cent. of the chord, yet a $\frac{1}{2}$ in. ice ridge at this point on a 100 in. chord wing reduces the maximum lift by 50 per cent. An improved de-icer extending over 15 per cent. of the chord is in an advanced stage of development.

The following table gives the improvement possible by adopting the new mechanical de-icer on a three-engined aircraft with a wing loading of 40 lb./sq. foot :—

	Icing conditions.		All ice removed.
	Old deicer.	New deicer.	
Stalling speed (m.p.h.), flaps up ...	135	109	102
,, ,, ,, down ...	90	84	79
Absolute ceiling (ft.)	13,000	17,400	20,700
Rate of climb (sea level) (ft./min.) ...	520	740	940

Alternative methods of removing ice by means of exhaust heat are receiving considerable attention. Although it appears that sufficient heat is available for this purpose, mechanical difficulties connected with corrosion, expansion and the presence of fuel tanks in the wings have still to be overcome. It is interesting to note that the presence of guide vanes in air scoops may cause a complete blockage by ice, whilst in the absence of the vanes the scoop will work satisfactorily under the same icing conditions.

Calculation of Diving Velocity. (E. Groth, Luftwissen, Vol. 7, No. 2, Feb., 1940, pp. 31-33.) (78/15 Germany.)

If the aircraft dives at a constant path inclination ϕ, the following equation represents the forces acting along the path (gravitational units) :—

$$(G/g)\,(dv/dt) = G \sin \phi - W \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where G = weight of aircraft.
V = path velocity.
W = resistance of aircraft.

The propeller thrust is neglected.

Putting $\lambda = (G \sin \phi)/(FC_w)$

where F = wing area
C_w = resistance coefficient and
$Y = V^2/2g$.

Equation (1) assumes the form

$$dy/dh = (\gamma/\lambda)\, Y - 1 \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where h = altitude
γ = density $= (1.2255)\,(288 - 0.0065\,h)/288^{4.255}$.

The author shows how this equation can be integrated in terms of certain exponential functions and gives graphs showing the diving velocity as a function of λ for a given change in h.

From equation (2) it appears that V is a maximum if $Y=\lambda/\gamma$, *i.e.*, $q=\lambda$.
Similarly

$$q_{max}=\lambda\ 1/\{\ 1+(\lambda/\gamma^2)\ (d\gamma/dh)\ \}$$

Thus the dynamic pressure reaches its maximum at a lower altitude than the velocity. The difference is, however, not very great and can generally be neglected in preliminary calculations.

Calculating Table (Nomograph) for High Speed Aircraft. (Luftwissen, Vol. 7, No. 2, Feb., 1940, p. 33.) (78/16 Germany.)

The nomograph gives the h.p. (N) required per kg. of aircraft for horizontal flight at various speeds at an altitude of 4 km., provided the following characteristics of the aircraft are known:—

$$v_{min},\ fs/G,$$
$$C_{wp}/C_{a\ max}\ \text{and}\ G/b^2$$

where G = weight of aircraft in kg.
f_s = parasite resistance area in m.^{2}.
b = span of aircraft in m.

In addition to giving the total N/G ratio as a function of the speed, the diagram enables a sub-division of the h.p. into profile, parasitic and induced components which is of great use in the preliminary stages of design.

Wind Tunnel Investigation of an N.A.C.A. 23030 Aerofoil with Various Arrangements of Slotted Flaps. (I. G. Recant, N.A.C.A. Tech. Note No. 755, March, 1940.) (78/17 U.S.A.)

An investigation was made in the N.A.C.A. 7 by 10-foot wind tunnel of a large chord N.A.C.A. 23030 aerofoil with a 40 and a 25.66 per cent. chord slotted flap to determine the section aerodynamic characteristics of the aerofoil as affected by flap chord, slot shape, flap position, and flap deflection. The flap positions for maximum lift, the positions for minimum drag at moderate and high lift coefficients, and the complete section aerodynamic characteristics of selected optimum arrangements are given. Envelope polars of various flap arrangements are included. The relative merits of slotted flaps of different chords on the N.A.C.A. 23030 aerofoil are discussed, and a comparison is made of each flap size with a corresponding flap size on the N.A.C.A. 23021 and 23012 aerofoils.

The lowest profile drags at moderate lift coefficients were obtained with an easy entrance to the slot. The 25.66 per cent. chord slotted flap gave somewhat lower drag than the 40 per cent. chord flap for lift coefficients less than 1.8, but the 40 per cent. chord flap gave considerably lower drag for lift coefficients from 1.8 to 2.5 and a larger value of the maximum lift coefficient. The drag coefficients at moderate and high lift coefficients were greater with both sizes of flap on the N.A.C.A. 23030 aerofoil than on either the N.A.C.A. 23021 or the N.A.C.A. 23012 aerofoil. The maximum lift coefficient for the deflections tested with either flap was practically independent of aerofoil thickness.

Studies of High Speed Aeroplanes. (F. Flader and E. R. Child, J. Aeron. Sci., Vol. 7, No. 6, April, 1940, pp. 235-43.) (78/18 U.S.A.)

Future high speed possibilities are examined by study of an aeroplane design with certain systematic variations in gross weight, wing loading and power. The factors used as a basis for the present design studies are:—High wing loading; entirely enclosed power plant; selection of optimum propeller, arranged as a pusher; mid-wing and tail arrangement with elimination of unfavourable interference; a cabin and windscreen enclosed within the normal contour lines of the fuselage; a finely streamlined fuselage shape; smooth body, wing and tail surfaces with suppression of all excrescences, wrinkles, rivet heads and skin laps; elimination of exposed scoops outside the normal contour lines of the aeroplane; elimination of exposed exhaust pipes; entire elimination of drag due to imper-

fectly retracted landing gear; selection of an optimum critical altitude; selection of best aerofoil section for the design maximum speed. An analysis is made of factors influencing propeller design, with a prediction of the propulsive efficiencies which may be obtained. The maximum attainable efficiency becomes less as speed and altitude are increased. Possibilities of increasing the indicated optimum propulsive efficiencies and the desirability of a variable gear drive device are briefly discussed. For aircraft designed according to conventional practice the maximum attainable speed is predicted to be possible of accomplishment within two years.

Magnesium for Aircraft Construction. (E. W. Conlon, J. Aeron. Sci., Vol. 7, No. 6, April, 1940, pp. 252-5.) (78/19 U.S.A.)

The present status of magnesium as a material for aircraft construction is similar to that of aluminum in about 1922, and the material is going through the same stages of development. Of the new alloys that are constantly being introduced, the designer should consider only those alloys rated A or B by the producer, as regards corrosion resistance, and alloys with low elongation as compared with aluminum alloys should be avoided.

Static tests referred to in this paper prove that magnesium alloys are satisfactory from a strength-weight standpoint, although much more research must be done to determine the most efficient forms, particularly extrusion and corrugation.

Full-scale static and service tests on wings, fuselages, or tail surfaces must be made to definitely prove that the material and method of surface protection are satisfactory under actual service conditions.

The practice of some manufacturers to use magnesium alloy sheet for fairings and cowlings appears to be a hard way of learning how to fabricate the material. These parts are difficult to form in any material, and strength is a minor consideration. It would seem more practical to first use magnesium sheet where little forming is required and where the high buckling strength is important, such as the covering of a wing or fuselage.

It appears to the author that the stamped butt-welded or cast wing and fuselage may offer as much possibility for low cost quantity production as any of the various plastics which have recently been suggested.

Modern Aircraft Valves. (A. T. Colwell, J.S.A.E., Vol. 46, No. 4, April, 1940, pp. 147-65.) (78/20 U.S.A.)

The development of American and European aircraft and automotive engine valves is reviewed and present types are described, including designs, materials, manufacturing processes, operation and maintenance. Three major developments are responsible for the low valve temperatures and long service under high output conditions of modern aero engine valves:—Development of the sodium-cooled valve, development of forging technique and cylinder head design. In addition, three minor developments are mentioned:—Adoption of T.P.A. austenitic steel for exhaust valves; use of stellite or a similar hard facing material puddled on the valve seat; and the use of T.P.A or silcrome X-9 for seat inserts. A much needed major development is a constant clearance aircraft valve mechanism which will meet all the requirements sought in America. Data from research work on improving gas flow in the valve ports are presented. Specific designs of valves discussed include Wright, Pratt and Whitney, Allison, Hispano-Suiza, Gnome-Rhone, Rolls-Royce, Bristol, Siemens, Junkers, Daimler-Benz, B.M.W., Bramo, Fiat, and Alfa-Romeo, as well as the Buick automobile valve.

Performance of Aircraft Spark-Ignition Engines with Fuel Injection. (O. W. Schey, J.S.A.E., Vol. 46, No. 4, April, 1940, pp. 166-76.) (78/21 U.S.A.)

Fuel injection offers two main advantages over the carburettor: Low volatile fuels (safety fuel) (which reduce the fire hazard) can be used and the combustion

chamber can be scavenged without the loss of fuel by the use of large valve overlap. Other advantages are improved starting, acceleration, manœuvrability, and distribution of fuel, as well as freedom from icing.

The National Advisory Committee for Aeronautics has investigated the factors influencing the injection of fuel into the engine cylinder. This investigation included the time of start of injection, the length of the injection period, the location of the fuel injection valve in the cylinder, the rate of fuel injection, the type of fuel spray, and the maximum injection pressure. Tests were conducted on cylinders with two and four valves having pent-roof, disc, and spherical combustion chamber forms. The performances of a modern air-cooled cylinder fitted with a carburettor, a fuel system injecting into the manifold, and a system injecting into the cylinder were investigated. Tests with different pumps and injection valves, with petrol and with four safety fuels of different volatility, both with and without valve overlap, were also made.

The power output for each of three methods of mixing the fuel and the air follows the volumetric efficiency closely and is higher with fuel injection into the cylinder than with a carburettor or manifold injection.

The minimum specific fuel consumption obtained in single-cylinder engine tests is the same with each method of mixing the fuel and air.

Junkers Inter-Cooler for Two-Stage Superchargers on Radial Engines. (Inter. Avia., No. 706, 16/4/40, p. 9.) (78/22 Germany.)

The two stages of the supercharger are mounted one behind the other on the rear cover plate, the second stage facing the engine.

The inter-cooler between the two stages is placed just outside the main engine cowl and surrounded by a short second cowl of larger diameter which finally joins the fuselage skin.

The air intake to the first stage faces forward and is placed in front of the engine inside the main cowling.

(The path of the cooling air is not described in the article. Judging from the diagram of the installation some measure of reversed flow is apparently adopted.)

The Effect of Piston Head Shape, Cylinder Head Shape, and Exhaust Restriction, on the Performance of a Piston-Ported Two-Stroke Cylinder. (A. R. Rogowski, C. L. Bouchard and C. Fayette Taylor, N.A.C.A. Tech. Note No. 756, March, 1940.) (78/23 U.S.A.)

A full-scale, three-dimensional, steady flow model of the two-stroke engine described in N.A.C.A. Technical Note No. 674 ($4\frac{1}{2}$ in. bore, 6 in. stroke), was constructed for the purpose of observing the scavenging air flow obtained with the various inlet port arrangements tested in the actual engine. Based on experience gained from correlation of the flow tests with engine tests, several piston head shapes were developed, and the most promising were tested in the engine. Several modifications of the successful round edge piston previously used, were also tested. Three types of cylinder head, spherical, cylindrical, and flat in cross section were tried, first in the flow model and then in the engine.

The principal conclusions are:—

1. The steady flow model is not a complete indicator of results to be expected in the engine.
2. The relative scavenging efficiencies of various piston and cylinder head shapes are little affected by scavenge ratio, above a scavenge ratio of 1.0.
3. It appears from a limited number of tests that the best port timing is not affected by piston or head shapes.
4. Within the range of scavenge ratios investigated, the difference in net power between the best and worst piston tested was within 12 per cent. The difference in net power between the best and worst cylinder head

tested was within 25 per cent. The most suitable port arrangement was used in all cases.

5. Swirl produced by partially blocking off the inlet ports on one side of the engine was detrimental to performance.
6. Some supercharging was obtained by reducing the height of the exhaust ports without changing their time of opening or closing, but only a small increase in net power was obtained in this way. Scavenging efficiency was reduced by excessive exhaust restrictions of this type.

Double Test Stand for Aero Engines. (C. Weltin, Z.V.D.I., Vol. 83, No. 47, 25/11/39, pp. 1237-8.) (78/24 Germany.)

When carrying out acceptance tests of aero engines on the test stand it is usual to first run-in the bearings and sliding surfaces by means of an electro-motor, while circulating oil and cooling agent, before running the engine under its own power for the continuous test under load. In order to save the expense of the electro-motor and its running costs a double test stand has been designed in which two test engines are mounted facing one another; the one running under its own power is provided with an airscrew, the flow from which drives a windmill attached to the second test engine which has to be run in. The latter is first " wind driven " for the required period, then run on its own power, and by simple interchange of propeller and windmill vane it is used in turn to run-in a new engine. The cooling systems of the two engines are connected up so that the heated cooling agent from the petrol-driven engine warms up the wind-driven engine. The oil systems of the two engines are separate. In most cases the wind alone is sufficient to provide the turning moment necessary to start up the second engine, which is previously decompressed. In absence of a valve for reducing the compression, an inertia starter or compressed air may be used.

Limitations of Single Stage Centrifugal Superchargers. (K. Kollmann, Luftwissen, Vol. 7, No. 3, March, 1940, pp. 54-61.) (78/25 Germany.)

The maximum supercharged height of single stage compression is determined by the following five factors:—

(1) Material of rotor.
(2) Compression efficiency (temperature rise).
(3) Manufacture (type of shrouding).
(4) Bearings.
(5) Method of drive (gears and clutches).

(1) In theory, any material can be utilised which has a ratio *yield point* of the same order as high duty steel (10.7) density.

It is possible to obtain this value with electron, whilst for dural the relative strength factor is as high as 13.6. From the point of view of fatigue, however, the light alloy is definitely inferior to steel. This difficulty can, however, be overcome by proper design. It is interesting to note that the Mercedes-Benz dural rotor only weighs 880 gm. whilst the R.R.Merlin rotor is stated to weigh 3,000 gm.

(2) Although by means of special devices (double shroud, rotating entry vanes, etc.) the D.V.L. have been able to achieve compression efficiencies as high as 83 per cent. at tip speed of the order of 230 m./sec., the efficiency falls to 68 per cent. at tip speeds of the order of 380 m./sec. and is thus no better than that given by a single shrouded impeller without entry vanes operating at the same tip speed. It is not considered likely that efficiencies higher than 70-75 per cent. will be realisable in the near future at high tip speeds. With a limiting induction temperature of 80°C. this means that single stage compression will give compensation up to a maximum altitude of 6-7 km.

(3) Manufacturing difficulties and considerations of weight definitely rule out complicated rotors such as the D.V.L. double shrouded type. The possible gain

in compression efficiency of such designs is limited in any case to relatively low tip speeds which are of no great practical interest.

(4) A useful empirical rule for roller bearings is given by the product of shaft diameter in mm. with r.p.m. This product should not exceed 600,000, *i.e.*, a 25 mm. shaft supported in roller bearings will run satisfactorily at 24,000 r.p.m. Speeds in excess of this are possible, but require extreme care in the fitting of the bearing and its lubrication. The practical limit of operation seems to be of the order of 30,000 r.p.m.

(5) With a compression efficiency of 70 per cent. the provision of 1.3 atmosphere absolute at 6 km. absorbs about 12-13 per cent. of the engine power. The work wasted near the ground is thus very considerable unless a variable speed drive is provided. An infinitely variable speed gear is the ideal solution.

The D.V.L. Torque Hub. (E. Gilbert and W. Ulrich, Luftwissen, Vol. 7, No. 3, March, 1940, pp. 64-66.) (78/26 Germany.)

The D.V.L. torque hub forms a complete unit with a three-bladed propeller, the blades of which are adjustable on the ground. It can easily be fitted to any engine of 500-1,500 h.p., and is sufficiently stiff not to lower the torsional vibration characteristics of the engine appreciably. Only in the case of heavily geared engines is the fundamental lowered by about 10 per cent. If necessary, a correction for the presence of the hub can easily be applied by the method of Behrens. The torque is recorded by means of the well known D.V.L. scratch method, the lines being sufficiently fine (0.01 mm.) to keep measuring errors below 1 per cent. The film is 12 mm. wide and of sufficient length (8 m.) to enable about 40 separate torque measurements to be taken (each lasting about two seconds). The film is moved electrically and provided with time base and engine revolution marks as well as a reference line for the torque measurements. The weight of the hub is 68 kg. without and 126 kg. with propeller blades.

The instrument is undergoing development for adopting it to variable pitch propellers of large power output.

Effect of Increased Finning of the Cylinders on Cooling of Air-Cooled Engines. (G. L. Sheremetov, Aeron. Eng., U.S.S.R., Vol. 14, No. 2, Feb., 1940, pp. 34-51.) (78/27 U.S.S.R.)

A theoretical investigation is made of the effect of variations in degree of finning on the heat transfer from an engine cylinder. Degree of finning is defined as the ratio of the total surface to the initial unfinned surface, and it is varied by independently altering the height of the fins, thickness of the fins and the distance between them. The purpose of the paper is comparative determination of the heat transfer from a cylinder of basic dimensions 160×100 mm. with various degrees of finning (7.65-89.38) during flight at 7,000 m. and $v_0 = 300$ km./hr., and for two different values of the cowling outlet aperture. The power expended on cooling during horizontal flight at 500 km./hr. at the same altitude was also calculated. It is found that the most effective means of increasing the finning is to increase the height of the fins; decrease in thickness and in distance between the fins does not give corresponding increase in heat transfer. For the conditions investigated the optimum thickness for steel fins was 0.8 mm. and for aluminium fins 0.4 mm. The optimum distance between the fins was 2 mm.

Calculation of a Cooling System for Aero Engines taking into Account the Compressibility of Air. (V. G. Nikolaenko, Aeron. Eng., U.S.S.R., Vol. 14, No. 2, Feb., 1940, pp. 52-66.) (78/28 U.S.S.R.)

Calculation of an aero engine cooling system must take into account air compressibility, and it is thus necessary to allow for variation in the physical properties of the air as it passes through the system, *i.e.*, variations in temperature,

density and pressure at all the characteristic cross-sections. The present theoretical study leads to the following main conclusions:—(1) Aerodynamic calculations must take into account heating up of the air on passing through the system. (2) The type of radiator mounting is of fundamental importance since it determines the external head drag. The optimum radiator dimensions and total power expended on cooling are fundamentally determined by this external drag. (3) A radiator of " zero " drag may be obtained either when the temperature difference is large (130-140°), or in the case of a temperature difference of 110-115° if the radiator mounting is of special design with small head drag. (4) The internal cooling drag of the cowling of an air-cooled engine, not taking into account the external drag at high velocity, nearly always creates reaction thrust, due to heating up of the air during its passage through, provided that the design is suitable to give correct deflection by the cylinders and that the outlet opening is correctly adjusted.

Freezing Points of the System Ethylene Glycol-Methanol-Water. (F. H. Conrad, E. F. Hill and E. A. Ballman, Ind. and Eng. Chem. (Ind. Ed.), Vol. 32, No. 4, April, 1940, pp. 542-3.) (78/29 U.S.A.)

With a view to producing an " optimum " anti-freeze agent from a mixture of methanol-ethylene glycol and water, to be superior in general properties to either alone, it is necessary to investigate the physical properties of this system over the temperature range to which anti-freeze mixtures are subjected. Freezing point determinations of this ternary system as a function of composition are as follows:—

Blend.		Freezing Point. with following % by weight of total blend in aqueous solution.				
Ethylene glycol. % by weight.	Methanol. % by weight.	10 °C.	20 °C.	30 °C.	40 °C.	50 °C.
100.0	0	−3.6	−8.3	−14.4	−22.6	−34.6
78.1	21.9	−4.2	−9.6	−16.1	−25.4	−37.9
65.0	35.0	−4.8	−10.2	−17.7	−28.0	−41.6
58.0	42.0	−5.0	−10.8	−18.9	−29.4	−44.1
49.6	50.4	−5.5	−11.7	−20.1	−31.1	−46.5
40.2	59.8	−5.7	−12.2	−21.0	−32.3	−47.7
29.8	70.2	−5.9	−12.9	−22.0	−33.6	−49.6
21.4	78.6	−6.3	−13.8	−23.6	−35.4	−52.0
12.1	87.9	−6.5	−14.8	−25.0	−37.9	−54.0
0	100.0	−6.8	−15.3	−26.3	−39.7	−54.9

Synthesis of Lubricating Oils (Part I), Condensation of Chlorinated Paraffin Wax with Aromatic Hydrocarbons. (W. R. Wiggins, T. G. Hunter and A. W. Nash, J. Inst. Petrol, Vol. 26, No. 197, March, 1940, pp. 129-145.) (78/30 Great Britain.)

Chlorinated paraffin waxes can be condensed with aromatic hydrocarbons, using metallic aluminium as catalyst to give viscous hydrocarbon oils. The oils have high viscosity indices, and the viscosity gravity constants are in many cases comparable to those of paraffin base oils. The Conradson carbon residues of the benzene and toluene condensation oils are extremely low. All the condensation oils have good oxidation resistance; after oxidation the change in colour is small, no asphalt is deposited, and the increase in viscosity is similar to that of commercial motor lubricants.

The Manufacture and Use of Tetra Ethyl Lead. (G. Edgar, J. Inst. Petrol., Vol. 26, No. 197, March, 1940, pp. 146-149.) (78/31 U.S.A.)

During 1939, the total yearly consumption of petrol in the U.S.A. was of the order of 2,000 million gallons, of which over 75 per cent (*i.e.*, 1,500 million gallons) contained varying amounts of tetra ethyl lead.

A very large plant has been put up at Baton Rouge for the manufacture of this dope according to the equation

$$4\ Pb\ Na + 4\ C_2H_5Cl = Pb\ (C_2H_5)_4 + 4\ Na\ Cl + 3\ Pb.$$

The pressures and temperatures during this reaction are moderate, but must be closely controlled to prevent wasteful and dangerous side reactions.

After the chemical changes are complete the tetra ethyl lead is distilled off in steam and the lead sludge reconverted into pig lead for making fresh sodium alloy. The necessary sodium is obtained from the electrolysis of salt whilst the chlorine produced at the same time is converted into hydrochloric acid by burning it with hydrogen. The hydrochloric acid is finally made to react with either ethyl alcohol or ethylene to produce ethyl chloride. Thus, with the exception of lead, all the raw materials for the manufacture are produced at the plant itself. The tetra ethyl lead, however, requires admixture both with ethylene dibromide and ethylene dichloride before it becomes serviceable. The latter chemical is bought in the open market whilst the ethylene dibromide is made at the Ethyl-Dow Plant (N.C.), using bromine extracted from sea water.

In the early stages the American plant supplied tetra ethyl lead both for home consumption and for export. Manufacturing plants are, however, now in operation both in Germany and in France and are planned for other countries. A share of the foreign demand is still supplied from the U.S.A.

Flame Speeds and Energy Considerations for Explosions in a Spherical Bomb. (E. F. Fiock, C. F. Marvin, Jr., F. R. Caldwell and C. H. Roeder, N.A.C.A. Report No. 682, 1940.) (78/32 U.S.A.)

Simultaneous measurements have been made of the speed of flame and the rise in pressure during explosions of mixtures of carbon monoxide, normal heptane, iso-octane and benzene, in a 10-inch spherical bomb with central ignition. From these records, fundamental properties of the explosive mixtures, which are independent of the apparatus, have been computed. The transformation velocity, or speed at which flame advances into and transforms the explosive mixture, increases with both the temperature and the pressure of the unburned gas. The rise in pressure has been correlated with the mass of charge inflamed to show the course of the energy development.

Comparable mixtures of the three hydrocarbon fuels expanded about the same amount upon burning and therefore developed about the same power, despite differences in the rate of burning. The addition of ethyl fluid produced no measurable change in flame speed over the range of conditions studied. None of the characteristics of normal burning seems to give a clue as to the relative tendency of fuels to knock. The observed values of pressure are lower than these calculated on the assumption that reaction goes to equilibrium within a very short distance behind the flame front. This fact, together with other independent evidence, points to a continued evolution of energy within gas that has already been traversed by flame.

The Accuracy of Altitude Determinations of Aircraft, based on Atmospheric Measurements. (H. J. Van Der Maas and J. H. Greidanus, Nat. Luchtvaartlab., Amsterdam, 1939, 30 pp.) (78/33 Holland.)

This report deals with the accuracy obtainable in determining the actual altitude of an aeroplane from measurements of pressure, temperature and humidity. The theoretical fundamentals of these atmospheric methods are discussed, particular attention being paid to the simplifying assumptions generally made in calculation, errors in measurement, the humidity of the atmosphere and of vertical air currents. Methods of measurement for pressure, temperature and humidity are described and instructions are given for carrying out the measurements during

flight, correction of the measurements and two methods of evaluation suitable for practical use. As regards total accuracy, it is stated that it should be possible to attain a relative accuracy of 0.3 per cent. of the actual altitude for 4,000 m. and over, and 0.7-0.8 per cent. at 1,000 m. Results are given of calibration tests of a precision altimeter and investigation of the error which may arise if altitude has to be determined on the basis of incomplete measurements.

Calibration of Dynamic Pressure Velocity Recorders and the Reduction of Their Readings to Actual Velocities. (S. Wynia and A. J. Marx, Nat. Luchtvaartlab., Amsterdam, Vol. 8, 1939, pp. 81-92.) (78/34 Holland.)

The velocity of an aircraft is usually determined from dynamic pressure, static pressure and temperature, on the basis of the flow theory; this calculation is only accurate in practice if the flow is treated as compressible. The scale of a dynamic pressure meter used as a speed indicator cannot therefore be graduated to always read the actual air speed, but is only correct for 760 mm. pressure and 0°C. The present report describes how the actual velocity can be deduced from the speed indicator readings by taking into account the compressibility of the air, and the results are given in a form ready for use in conjunction with a speed indicator, free from instrumental error, calibrated for 0m. altitude in the standard atmosphere.

Flight Ray, a Multiple Instrument Indicator. (P. R. Bassett and J. Lyman, J. Aeron. Sci., Vol. 7, No. 5, March, 1940, pp. 199-204.) (78/35 U.S.A.)

The present paper is a progress report on the development of an instrument by means of which the information from those flight instruments constantly requiring the pilot's attention is concentrated into an easily readable diagram on the fluorescent window of a cathode ray tube. Attitude and positional information and air speed are shown diagrammatically. A switching arrangement couples each primary flight instrument in turn to the cathode ray tube. The switching is carried out at a rate well above the threshold frequency so that the image gives for all practical purposes a continuous picture of the movements of the aeroplane as shown by the actuating instruments. The arrangement of the information, flight tests, and various problems encountered in the development along with their tentative solutions are described.

The Telegon System of Remote Instrument Indication by Self-Synchronous Electric Motors. (A. G. Binnie, J. Aeron. Sci., Vol. 7, No. 5, March, 1940, pp. 211-212.) (78/36 U.S.A.)

The use of self-synchronous electric motors for duplicating motion at some point distant from its source has been well known for some time.

The application of this method to the distant reading of aircraft instruments requires special care and leads to the characteristic feature of the Telegon system. In this system, all slip rings are avoided by having the primary coil fixed and the soft iron armature supported on jewelled bearings. The secondary circuit consists of two phase windings placed at right angles. Two such instruments are connected so that the primary coils are in series, the phase windings forming a closed circuit, the centre of which is attached to one pole of the A.C. supply. A displacement of the rotor of one unit by the indicating instrument will on account of the unsymmetrical shape of the armature cause a change in the induced magnetic field. Currents are now induced in the phase windings so as to render the magnetic patterns of the two motors identical with the result so that the second rotor will turn into step with the first, *i.e.*, the reading of the measuring instrument is transmitted. Each telegon unit absorbs about 1.25 watt, weighs 4 ounces, has dimensions $1\frac{1}{2} \times 1\frac{1}{2}$ inches and will operate on any A.C. voltage between 24 and 120 and 300-800 cycles.

The 1-Phase Magnet Motor. (T. Buchhold, E.T.Z., 4th January, 1940, pp. 7-10.) (78/37 Germany.)

The author discusses the nature of the electrical power characteristic of magnet motors, such as are used for driving synchronous clocks, the problem of harmonics and the necessary reactive VA. He also investigates under what conditions such a motor is capable of running at different synchronous speeds. He deals in particular with the following: Bi- and multi-polar designs, principle of operation of the magnet motor, influence of harmonics and power input, possible speeds, useful torque, recorded current curve.

Illustrated with six diagrams.

(Abstract supplied by Metropolitan Vickers Research Department.)

The "Guidonia" Aircraft Speed Indicator. (Les Ailes, No. 977, 18/4/40, p. 5.) (78/38 Italy.)

This instrument has been designed to cover accurately the very large speed range between landing and maximum speeds.

The usual aneroid box, the inside of which is subjected to the total pressure whilst the outside is under the influence of the static pressure, deflects relatively more at low than at high aircraft speeds. In the new instrument the motion of the diaphragm is transferred to the pointer by means of an off-set lever which rotates a toothed sector engaging with a gear on the pointer. In order to maintain sensitivity, the geared sector is in turn off-set with respect to the lever so that the effective multiplication is increased with increasing deflection and thus produces a more uniform scale.

Materials for Slack Diaphragms. (T. Puschmann, Forschung, Vol. 2, No. 1, Jan.-Feb., 1940, pp. 35-42.) (78/39 Germany.)

So-called "Slack" diaphragms made of rubber, leather, or synthetic materials, are frequently employed in measuring and control instruments. Up to now no systematic experiments have been carried out on the suitability of such materials for work of this kind and hence the choice was rather haphazard. The author first investigates the conditions under which such slack membranes are employed and then describes a number of instruments for the testing of such materials as regards deflection under load, hysteresis and the effects of temperature and moisture. It appears that synthetic leather (treated with castor oil) is the most suitable material for the small pressure range generally required (20-50 mm. water). Balloon cloth is nearly as good. Gold beater skin and synthetic rubber are definitely unsuitable.

The D.V.L. Accelerometer. (H. Freise, Luftwissen, Vol. 7, No. 2, Feb., 1940, pp. 30-31.) (78/40 Germany.)

The D.V.L. accelerometer weighs about 1 lb. and covers the range -4 g. to $+8$ g. The dimensions of the instrument are:—

Diameter, 80 mm.
Depth, 100 mm.

The accelerometer is intended to measure acceleration at right angles to the longitudinal axis of the aircraft such as occurs when pulling out of a dive. It consists of a mass held between two horizontal springs and free to move in the required direction.

If

N_0 = natural frequency of undamped system (about 11 vibrations/sec).
a = deflection of mass.
b = acceleration.

We have

$$a = b/(2\pi N_0)^2$$

provided the damping is sufficient (logarithmic decrement 1.3 at 24°C.).

The mechanism of the instrument is simple and robust. The oscillating mass is immersed in a viscous liquid, a rubber diaphragm providing the necessary seal for the racket transmission to the indicating pointer. The latter is provided with maximum and minimum indicators, either of which can be reset by hand.

Some Stress-Strain Studies of Metals. (R. L. Templin and R. G. Sturm, J. Aeron. Sci., Vol. 7, No. 5, March, 1940, pp. 189-98.) (78/41 U.S.A.)

(1) An annealed or heat-treated metal which has not received any cold working subsequent to the thermal treatment given it, has substantially the same stress-strain curve in compression and in tension. The characteristic stress-strain curve for aluminum alloys in this condition shows a gradually rounded shape above the proportional limit with no sharp knee in the curve.

(2) Uni-directional cold work such as stretching beyond the original yield strength gives dissimilar stress-strain curves in tension and compression, the yield strength being raised higher in the direction of the stress used in producing the cold work.

(3) The characteristic tensile stress-strain curve for aluminum alloys which have been stretched beyond the original yield strength is one which lies distinctly higher than that for the unstretched material and which shows a relatively sharp knee just below the yield strength.

(4) The characteristic compressive stress-strain curve for aluminum alloys which have been subjected to uni-directional cold work by stretching is substantially the same as that for the unstretched material.

(5) The characteristic shape of stress-strain curve for material which has been subjected to uni-directional cold work in compression is just the reverse of that for stretched material, that is, the sharp knee and the large increase in yield strength occurs in the compressive stress-strain curve, while the tensile stress-strain curve retains substantially the same shape as for the material in the condition of zero cold work.

(6) Poly-directional cold working of aluminium alloys, such as is produced by forging, cold rolling, drawing through a die, or extruding, results in tensile and compressive stress-strain curves which lie distinctly above those for the material in the condition of zero cold work, but which are substantially the same shape as those for the metal in the condition of zero cold work. The characteristic knee of the stress-strain curve which accompanies uni-directional cold work is entirely absent if the cold working has been truly poly-directional.

(7) In the case of aluminium alloys, cyclic uni-directional cold work produced by subjecting a piece of metal alternately to axial tensile and compressive forces above the elastic range tends to produce the same general stress-strain characteristics as those produced by poly-directional cold working, provided the degrees of cold work in the two halves of each cycle are substantially equal.

(8) Cyclic uni-directional cold working produces no significant changes in the shape of the stress-strain curves of a copper rod, but completely alters those of the brass and magnesium alloys tested. In all cases there is a marked reduction in the proportional limit of the material in both tension and compression, often to the point where there is no longer any initial straight-line portion of the stress-strain curve.

Brittle Lacquers as an Aid to Stress Analysis. (A. V. de Forest and G. Ellis, J. Aeron. Sci., Vol. 7, No. 5, March, 1940, pp. 205-8.) (78/42 U.S.A.)

The fracture of brittle coatings has long been recognised as a method of checking strain distribution. Flaking of brittle mill scale at the yield point of local areas was used in the testing of the first wrought iron bridges. More

recently brittle resin coatings which will fracture within the elastic range of most materials have been developed to give good qualitative pictures of strain distributions.

The present work describes an improved brittle coating in the form of a sprayable lacquer which air dries over night to form a coating of uniform brittleness within the limits of thickness of three to eight thousandths of an inch. A calibration method is described whereby quantitative values of strain may be estimated within fifteen per cent.

Effective Widths of Stiffened Panels Under Compression. (J. R. Fischel, J. Aeron. Sci., Vol. 7, No. 5, March, 1940, pp. 213-16.) (78/43 U.S.A.)

A general equation is obtained for the effective width of flat sheet in semi-monocoque structures. This equation is similar to that given by von Kármán, differing only in the magnitude of the buckling constant.

The effects of a decreasing modulus of elasticity at high stresses, inter-rivet buckling, and differences in strength between the stiffener material and the sheet material are taken into account. Curves of effective width of sheet versus stiffener stress are plotted to enable the designer to apply the theory readily to the design of structures.

The close agreement between the theory and test data substantiates the several assumptions made in developing the formulæ.

Heat Treatment of Aluminium Alloys. (L. W. Kempf, Metal Industry, 29th March, 1940, pp. 288-90.) (78/44 Great Britain.)

Most of the article is devoted to the fundamentals of solution and precipitation hardening processes. The alloying of aluminium with elements of nearly similar electro-potential value, and the formation of a homogeneous single phase material, give the best corrosion resisting properties. Precipitation hardening leads generally to the formation of polyphase systems, and a solution hardened metal shows distinct advantages. Fatigue resistance increases with higher concentrations of the alloying elements in solid solution, while electric resistivity shows a similar variation. There follows a discussion on the stability of quenched aluminium alloys which is to be continued in a subsequent article. Illustrated with three graphs.

(Abstract supplied by Metropolitan Vickers Research Department.)

Repair Welding, Brazing and Soldering. (E. R. Thews, Metal Industry, March, 1940, pp. 149-153.) (78/45 U.S.A.)

The author commences with a description of preheating furnaces of cases where preheating of the whole specimen is feasible. He goes through the whole welding procedure, the cutting out of the fault and selection of the flame, to the final heating and machining and points out that welding, brazing and soldering each have distinct fields of use in repair work, but favours brazing wherever it is possible. Similarly, fluxes and solders should be individually selected for the job, and especial care should be devoted to exclusion of solder impurity. Illustrated with two diagrams.

(Abstract supplied by Metropolitan Vickers Research Department.)

Tentative Standard Methods for Mechanical Testing of Welds. (Welding Journal, March, 1940, pp. 201-11.) (78/46 Great Britain.)

These standards have been prepared by the Committee on Standard Tests for Welds of the American Welding Society. The report deals with the weld metal, butt welds and fillet welds. Weld metal is to be tested by its density, soundness as shown by an etch test, and its tensile strength; butt welded joints by a nick-bend test, a guided-bend test, tensile strength and ductility; fillet welded joints by a weld-break test, and shearing strength in transverse and longitudinal direc-

tions. The report gives dimensioned diagrams of the specimens and procedure and explains the units and significance of the results obtained from such tests. Illustrated with 19 diagrams.

(Abstract supplied by Metropolitan Vickers Research Department.)

Shaping Edges for Welding. (H. E. Rockefeller, Steel, 11th March, 1940, pp. 60-4.) (78/47 Great Britain.)

The article is concerned with the preparation of edges before welding, and explains how single nozzle oxy-acetylene torches may be made to give full " U " or " J " grooves in a single pass. It explains a plate-riding device, the use of which allows the proportions of the grooves to be varied, and it proceeds to discuss the simultaneous use of two or more nozzles. The positioning of the plates to be cut is important, and the merits of different methods of setting up are discussed. Illustrated with nine photographs and two diagrams.

(Abstract supplied by Metropolitan Vickers Research Department.)

Research on Surface Finish. (Schlesinger, Mechanical World, 29th March, 1940, pp. 269-71.) (78/48 Great Britain.)

The article is a summary of the preliminary report of the Research Department of the Inst. Prod. Engrs. The object of the research was to select a suitable unit for measuring surface finish, to suggest symbols for drawings, and to compare methods of observing finish. The report gives a general description of the range of surfaces submitted to test, and points out the variety of finishing tools and methods of abrasion that are in use. The article will be continued in a later issue. Illustrated with two photographs, three diagrams and one table.

(Abstract supplied by Metropolitan Vickers Research Department.)

On the Crippling Load of a Strut. (C. E. Inglis, J. Inst. Civ. Engs., Vol. 14, No. 6, April, 1940, pp. 205-226.) (78/49 Great Britain.)

In the case of an isolated triangular framework :—

(1) The terminal bending moments in the members of a framework with stiff joints may be greatly influenced by changes in flexibility due to axial loading; this is particularly the case when the members are slender and are loaded nearly up to the point of failure.

(2) Owing to the change in flexibility due to axial loads, the principle of superposition does not apply. Terminal bending moments are not proportionate to the applied loads, and as the loading of a framework increases they may actually diminish and change sign.

(3) Secondary terminal bending moments which act in the same direction are less destructive to a compression member than these same terminal bending moments acting in opposite directions.

(4) The B.S.I. formula, $p = 9\,(1 - 0.0038\,l/K)$ tons per square inch, or the A.E.R.A. formula, $p = 15{,}000 - l^2/4\,k^2$ lb. per square inch, prescribing the safe axial load for a compression member with riveted ends, provide a margin of safety sufficiently wide to accommodate the secondary stresses which are likely to be induced in any ordinary stiff-jointed framework.

Behaviour of Polyvinyl Chloride Plastics Under Stress. (J. J. Russell, Ind. and Eng. Chem. (Ind. Ed.), Vol. 32, No. 4, April, 1940, pp. 509-12.) (78/50 U.S.A.)

The procedure used to determine the tensile stress-strain diagrams for polyvinyl chloride plastics over a temperature range of $-50°$ to $+80°$C. is described. For compounds containing little or no filler, Poisson's ratio is about 0.5. This value is practically the same as that obtained for soft vulcanised rubber. The stress-strain curves change in shape as the temperature is lowered and ultimately reduce

to the "brittle point." This temperature is characteristic for each composition of plasticised polyvinyl chloride: The stress vs. temperature plot consists of at least two portions: a lower temperature portion exhibiting a linear relation between stress and temperature, and a higher temperature portion following an exponential relation. The heats of activation thus derived are of the same order of magnitude as those obtained for a number of pure metals.

Effect of Acceleration on the Human Organism. (V. Streltsov, Aeroplane, U.S.S.R., No. 10, Oct., 1938, pp. 28-31.) (78/51 U.S.S.R.)

The effect of acceleration on the human organism is mainly on the heart and vascular system, the maximum effect being produced when the force acts from feet to head. The work of Kudenko and Chirkin, at the Lenin Institute of Physical Culture, has shown that by suitable physical training it is possible to accustom the heart and vascular system to accelerations which would normally cause hæmorrhage. Special training equipment has been designed and special courses of exercises worked out. Two examples of the sequence of exercises are given. Special equipment includes a "Triplex" consisting of three revolving rings mounted one within the other. The pupil attaches himself to the inner ring and by changing the position of his centre of gravity sets it in rotation; at the same time the two other rings are set in rotation in two other planes mutually at right angles. The pilot thus experiences complicated conditions of acceleration.

Technology and Medicine in Aviation. (J. Jongbloed, Luftwissen, Vol. 7, No. 2, Feb., 1940, pp. 21-23.) (78/52 Germany.)

Aircraft performance (speed, manœuvrability, rate of climb, altitude) is determined not only by the technical excellence of the aircraft as such, but also by the limitations of the human organism. The technical advantages of flying at great altitudes are well known, but although machines can now be designed to operate under such conditions, the proper protection of crew and passengers still leaves much to be desired. Protection against cold is relatively simple, but lack of oxygen concentration is more difficult to guard against. The wearing of masks is cumbersome and it cannot be expected that the ordinary passenger will put up with such discomforts for any length of time and the author considers that some form of pressure cabin will become essential for all operations above 3,000 m. At the lower altitudes, leaks are not dangerous and can be balanced by an excess of oxygen supply over a short period. It is only by gaining experience under these conditions that the reliability of such devices can be improved to the point when flight at greater altitudes (of the order of 10,000 m.) can be carried out in safety.

Apart from altitude, the human organism is sensitive to acceleration. For this reason passenger-carrying aircraft do not carry out violent manœuvres. High acceleration cannot, however, be avoided in aerial combat and it is important to know not only what maximum the human organism can stand, but also what precautions can be taken to minimise deleterious effects. These effects vary considerably with the direction of the acceleration relative to the foot/head axis of the body. The most dangerous case arises if the acceleration is along the body towards the head, when acceleration in excess of 3 to 4 g. produces already far-reaching physiological effects. These limits can be raised to some extent by assuming a crouching position so that the distance between the heart and the brain is reduced.

If the acceleration acts transversely to the body, much higher acceleration (of the order of 10-15 g.) can be supported for short periods.

From the above it appears futile to design aircraft with large factors of safety unless the crew can be placed in such a position as to be safeguarded as much as possible against the effects of excessive acceleration.

The Physiological Effect of Large Accelerations. (S. Ruff, Luftwissen, Vol. 7, No. 2, Feb., 1940, pp. 24-29.) (78/53 Germany.)

The following four factors decide the effect of acceleration on the human body :—

1. Magnitude of acceleration ;
2. Time of action ;
3. Direction of acceleration ;
4. Physical state of individual.

In the case of a person seated in an aircraft, the centrifugal force acts in the direction head → seat and the blood pressure is thus reduced above the heart and increased below it. This would not affect the circulation materially if all the arteries and veins were rigid and maintained their shape. Unfortunately the veins are very elastic and under the effect of the new pressure distribution a considerable quantity of blood is stored in the expanded arteries without taking part in the circulation. This in its turn reduces the oxygen supply to the brain which first affects the vision (black-out) and soon afterwards produces loss of consciousness. It is interesting to note that the optical effects disappear almost immediately if the centrifugal force is removed. Loss of consciousness, however, persists for at least 3 to 5 seconds after the acceleration has already ceased. Experience indicates that a healthy individual occupying the normal seat in an aircraft can withstand an acceleration of 5-6 g. for a period of 3-4 seconds without ill effects. This means that the radius of a turn must not be less than about 500 m. at a speed of 600 km./hour and naturally entails a great sacrifice in manœuvrability. Many attempts have been made to increase the resistance of the human body to acceleration. A theoretical solution would be provided by immersing the body in a liquid of equal density and sealed in a rigid shell.

This is clearly impracticable, but provision of bandages round legs and stomach is certainly beneficial and raises the safety limit by $\frac{1}{2}$ to 1 g. (period of action 3-4 seconds). Even better results are obtainable if a meal is taken some time before exposure to acceleration. This is due to the fact that the digestive operation automatically produces an accumulation of blood in the intestine region and thus prevents large scale displacements in the blood stream. The breathing of CO_2/O_2 mixtures is also beneficial since it facilitates the blood circulation in the brain. Placing the legs high and crouching forward also reduces the harmful effects of acceleration, and by employing all the measures detailed above it is possible to subject the aircraft crew to an acceleration of 7-8 g., provided the duration of application of the force does not exceed 3-4 seconds. Further improvements are only possible if the normal seating in the aircraft is given up in favour of a prone position. Laboratory experiments have shown that under these conditions accelerations as high as 10-14 g. can be supported for 2-3 minutes without ill effects. These conclusions have been confirmed by actual flight experiments utilising a specially built glider. In conclusion, the author calls attention to an alternative solution. Experiment has shown that the human body can stand very high accelerations provided the time of application is less than one second (26 g. for 1/5 second). It is not yet possible to say whether the aircraft can be pulled out of a dive in such a short period of time.

The Basis and Aims of Research in Applied Heat. (E. Schmidt, Forschung, Vol. 11, No. 1, Jan.-Feb., 1940, pp. 1-6.) (78/54 Germany.)

The necessary tools for most thermodynamic investigations are provided by the so-called three laws of thermodynamics (Mayer, Clausius and Nernst), but much requires to be done on the experimental side. Thus, really satisfactory thermodynamic data are only available for steam. Tables for other engineering substances such as air, NH_3, SO_3 and CO_2 are fairly satisfactory, but a whole group of new substances now being employed in the refrigerating industry urgently

need fuller experimental investigation. The same applies to the thermodynamics of mixtures and the whole problem of diffusion.

Heat transfer in fluids is intimately connected with turbulence and boundary layer phenomena. The effect of Mach number on these processes still requires experimental investigation.

Although the practical application of combustion is intimately linked up with the history of the human race, the complexity of the phenomenon has only recently been appreciated. The utilisation of the combustion process in prime movers has led to further problems dealing with heat loss and combustion control, many of which still require scientific investigations.

General Laws Governing Heat Conduction (Effect of Nature of Substance and State of Aggregation). (A. Eucken, Forschung, Vol. 11, No. 1, Jan.-Feb., 1940, pp. 6-20.) (78/55 Germany.)

The heat conductivity λ is defined by the equation

$$Q = \lambda F \, (dT/dx)$$

where Q = quantity of heat transmitted per sec.,
F = area of surface,
dT/dx = temperature gradient.

1. With the help of the kinetic theory, it is possible to calculate λ for gases to within 1 or 2 per cent. if the viscosity and specific heat is known.

The resultant equation is very simple, *i.e.*,

$$\lambda = (4.47/C_v + 1) \, c_v \eta$$

where C_v = specific heat at constant volume per gm. molecule, and
c_v = specific heat at constant volume per gm.,
η = viscosity.

2. In the case of liquids, theory indicates an equation of the form

$$\lambda = \delta \rho c \rho u$$

where u = velocity of sound,
δ = mean separation between molecules.

Agreement with experiment is here not so good and discrepancies up to 100 per cent. may arise.

3. At the moment we are unable to calculate the conductivity of non-metallic substances by making use of other physical constants. Theory enables us, however, to draw some general conclusions and the great drop in conductivity of amorphous substances compared with crystals can be explained.

4. The calculation of λ for metals, if the electrical conductivity is known, is based on the Wiedemann-Franz-Lorenz law. The author shows that by applying a small correction factor, it is possible to calculate the thermal conductivity of any member of a group of alloys from the corresponding electrical conductivity within an accuracy of 1-2 per cent.

Non-Steady Method for Determining the Thermal Conductivity of Liquids. (J. Weishaupt, Forschung, Vol. 11, No. 1, Jan.-Feb., 1940, pp. 20-34.) (78/56 Germany.)

Experimental study of the thermal conductivity of liquids is rendered difficult by the fact that convection must be avoided. One method of doing this consists in utilising only very thin layers of liquid (so-called guard ring method). The experiment is, however, difficult and not free from error unless very special precautions are taken. Pfrichm has lately proposed (Z.V.D.I., Vol. 82, 1938. p. 71) a new non-steady method which appears to have considerable advantages. The method is based on the following considerations: A vertical wire is immersed in an infinite liquid and receives instantaneously at time $\tau = 0$ the quantity of heat

W_0 (K cal./metre). A time $\tau = \tau$, the temperature in the liquid at a distance r from the wire is given by

$$t = (W_0 e^{-r^2/4a\tau}) / (c\gamma 4\pi a\tau)$$

where c = specific heat of liquid,
γ = density,
a = temperature conductivity.

If a succession of heat quantities at regular time intervals is utilised, t will have to be obtained by summation. By reducing these intervals indefinitely, we finally obtain the case of the wire being heated by a constant current and the temperature becomes

$$t = (N_0/l_0)\,(1/4\pi\lambda)\left[-\int_{\phi}^{\infty} (e^{-\phi}/\phi)\, d\phi \right]$$

where $\phi = r^2/4a\tau$,
λ = conductivity,
$N_0 = K$ cal./hour generated,
l_0 = length of wire.

If the wire is sufficiently thin, t as measured from its resistance agrees with the temperature of the liquid on its surface, *i.e.*, r = radius of wire.

The author gives details of an apparatus based on these principles and employing a gold wire 0.07 mm. diameter and about 20 cm. long. The electrical circuit is described and various sources of error are discussed. These are mainly connected with convection and the possibility of turbulence arising. In view, however, of the mean temperature difference between wire and liquid being very small, errors arising from this cause are likely to be small. The new method is particularly suited for liquids which are electrical insulators. It can, however, be extended to semi-conductors or weak electrolytes.

LIST OF SELECTED TRANSLATIONS.

NOTE.—Applications for the loan of copies of translations mentioned below should be addressed to the Under-Secretary of State (R.T.P.), Air Ministry, Dept. Z.A., London, W.C.2, and will be loaned as far as availability of stocks permit. Suggestions concerning new translations will be considered in relation to general interest and facilities available.

Lists of selected translations have appeared in this publication since September, 1938.

TRANSLATION NUMBER AND AUTHOR.		TITLE AND REFERENCE.
		AIRCRAFT AND ACCESSORIES.
1011	Possio, C.	*Determination of the Aerodynamic Forces Corresponding to Small Oscillations of the Aeroplane.* (Turin Polytechnic, Aeronautical Laboratory, Report No. 118, Dec., 1938, XVII.) (L'Aerotecnica, Vol. 18, No. 12, Dec., 1938, pp. 1323-1357.)
1013	Possio, C.	*On the Determination of the Aerodynamical Coefficients which Affect the Stability of the Aeroplane.* (Turin Polytechnic, Aeronautical Laboratory, Report No. 122, Jan., 1938, XVI.)
1025	Schepisi, G. A. G. ...	*Note on the Calculation of the Critical Velocity of Cantilever Wings for Flexural and Torsional Vibrations.* (L'Aerotecnica, Vol. 19, No. 11/12, Nov./Dec., 1939, pp. 1025-1037.)
		AERO AND HYDRODYNAMICS.
1001	Giovannozzi, R. ...	*The Wind Tunnel of the Mechanical Department of Pisa University.* (L'Aerotecnica, Vol. 19, No. 7, July, 1939, pp. 737-759.)
1014	Possio, C.	*Aerodynamic Forces on a Lifting Surface in Variable Motion.* (Turin Polytechnic Aeronautical Laboratory, Report No. 127, June, 1939, XVII.)
1015	Eula, A.	*The Influence of the Reynolds Number at Large Mach Numbers.* (L'Aerotecnica, Vol. 20, No. 1, Jan., 1940, pp. 20-9.)
1021	Jung, I.	*Heat Transmission and Frictional Resistance for the Flow of Gas in Tubes at High Velocities.* (V.D.I. Forschungsheft, No. 380, Sept.-Oct., 1936.) (D.B.R. Pamphlet 217/1.)
1026	Poggi, L.	*Investigations on a High Speed Wind Tunnel Type Working on an Injection System with a Jet of Steam as a Fluid.* (L'Aerotecnica, Vol. 19, No. 11/12, Nov./Dec., 1939, pp. 1038-1049.)

TRANSLATION NUMBER AND AUTHOR.			TITLE AND REFERENCE.
1027	Pistolesi, E.	...	*On the Flow of Compressible Fluids, about a Circular Cylinder.* (L'Aerotecnica, Vol. 19, No. 11/12, Nov./Dec., 1939, pp. 1064-1068.)

MISCELLANEOUS.

1018	Fuchs, F. ...	...	*Radio Accessories Shown at the 16th German Radio and Television Exhibition.* (H. F. Technik, Vol. 55, No. 1, Jan., 1940, pp. 1-9.)
1020	Kuhm, M. ...	...	*Effects of Piston Ring Material on Running Time.* (Jahrbuch der deutschen Luftfahrtforschung, Vol. 2, 1938, pp. 87-96.)

STUDY OF AIRSCREWS FOR HIGH SPEED AEROPLANES.

By Lucio Lazzarino.

Corrections.

We have had a letter from the author of the above paper saying that there were a number of printing errors in the original paper in " L'Aerotecnica " (as published in July, 1939). The corrections were given in the November-December issue of " L'Aerotecnica " and are printed below :—

Equation 18 should read

$$T = 4\,\pi\rho \int_{R_1}^{R} (V_0 + v')\, v' r dr \quad . \quad . \quad . \quad . \quad (18)$$

Equations 19, 20, 21 and 22, for $\pi\rho$ read $2\,\pi\rho$ in every case.

The table on page 334, bottom of page, should be as follows :—

η_i	R (m.) \ ξ	0.3	0.4	0.5	0.6	0.7
0.971	0.8	0.767	0.787	0.795	0.787	0.767
0.977	0.9	0.764	0.786	0.796	0.786	0.764
0.982	1.0	0.758	0.781	0.792	0.781	0.758
0.985	1.1	—	0.773	0.784	0.773	—
0.987	1.2	—	0.765	0.765	0.765	—
0.989	1.3	—	—	—	—	—
0.990	1.4	—	—	—	—	—

Page 335.

First two lines, for " lies between $R = 0.9$ and $R = 1$ " read " is approximately $R = 0.9$."

Line 8, for 0.778 read 0.796.

Line 10, for 2.00 read 1.80.

Page 336.

In table the figures in the last two rows should be

Efficiency of two counter-rotating airscrews $\xi = 0.5$...	0.795	0.796	0.792	0.784	0.774	—	—
Efficiency of airscrew with fixed counter-screw $x = 0$ ...	0.693	0.704	0.709	0.708	0.705	—	—

Page 337.

The table at the top of the page should read :—

Airscrew diameter (m.)	2.00	2.20	2.40	2.60	2.80	3.00	3.20	3.40
Efficiency of single airscrew	—	—	—	—	0.745	0.754	0.756	0.749
Efficiency of two counter-rotating airscrews $\xi = 0.5$	0.801	0.802	0.803	0.799	0.793	0.784	—	—
Efficiency of two ditto for $\xi = 0.4$	0.793	0.793	0.794	0.788	0.782	0.766	—	—

Immediately below the table, for 0.778 read 0.796 and for 0.792 read 0.803.

Figs. 3, 4 and 5 of the original paper are altered as below::—

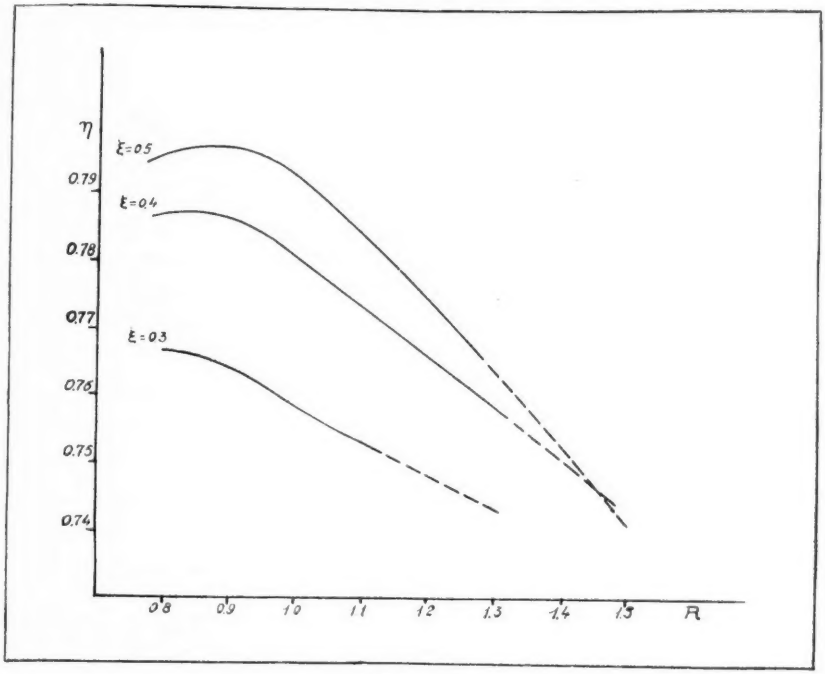


Fig. 3.

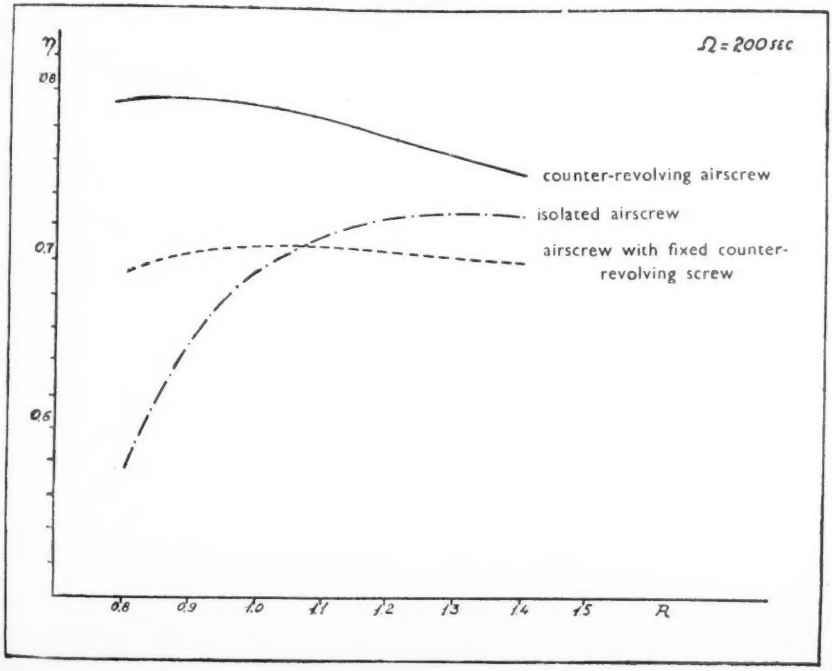


Fig. 4.

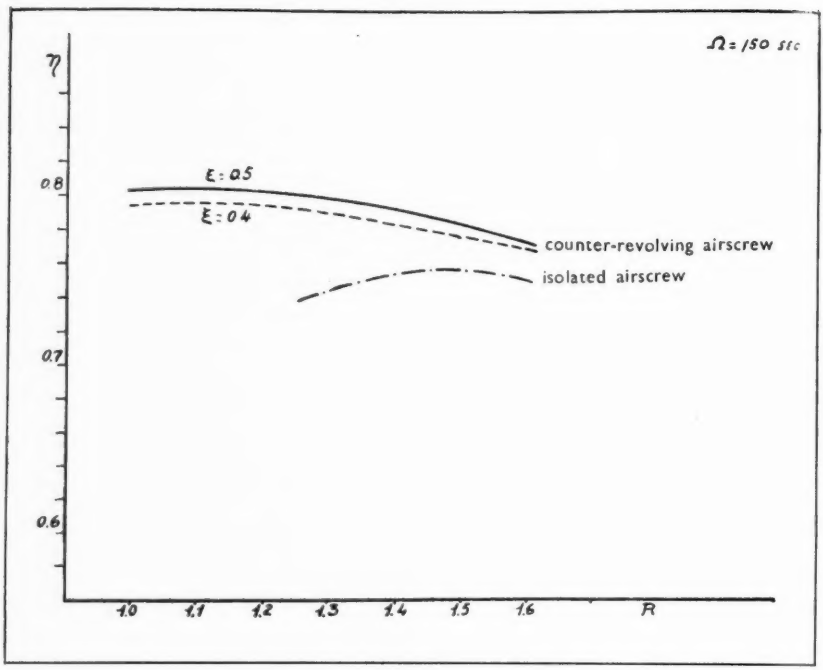

Ω = 150 sec
η
0.8
0.7
0.6
ξ = 0.5
ξ = 0.4
counter-revolving airscrew
isolated airscrew
1.0
1.1
1.2
1.3
1.4
1.5
1.6
R

Fig. 5.

REVIEWS.

NAVIGATOR'S LOG BOOK AIRPLANE NO. 25.

Facsimile and translation into English. State Art Publishers, Moscow and Leningrad. 1939.

This is a most beautifully produced facsimile of the Navigator's Log Book of Aeroplane No. 25, which made the first non-stop flight from Moscow, over the North Pole, to the United States of America.

It was on June 18th-20th, 1937, that three Soviet airmen, Chkalov, Baidulov and Belyakov, made the remarkable flight which was at first greeted with scepticism, but afterwards hailed by the world as an outstanding achievement.

The start was made at 1.04 a.m., Greenwich time, from Moscow, and here is reproduced the log of the flight. The first real difficulty the plane encountered was ice formation over the Kola Peninsula. Belyakov observes here that the theory that ice would not form at such a low temperature as $-24°C.$ was proved wrong; luckily the ice formation did not reach danger point.

The plane was in almost constant communication with ground stations throughout the flight, helping the navigation over the endless trackless wastes considerably.

At 4.15 a.m., on June 19th, the region of the North Pole was reached, and almost exactly twelve hours later the shores of Canada, at Pearce Point, were sighted. Towards the end of the day the oxygen supply gave out so that the fliers could no longer keep at a great height and were forced down below the clouds, to sight the Pacific Ocean. The plane finally came down on the military field at Vancouver, after being in the air 63 hours 16 minutes and covering a distance of 5,670 miles.

Such, extremely briefly, is the story of the flight. The details themselves of its accomplishment, in the Navigator's Log Book, are almost as brief. Here are one or two:—

June 18, 1937. 15.48. On the left clouds covering us like a broad brimmed hat.

June 18, 1937. 16.22. Flying over the devil alone knows what layer of clouds.

June 19, 1937. 4.15. The Pole. Observing the ice fields of the Pole, white with cracks, waterways and hummocks.

June 19, 1937. 12.40. The water pipe burst. The water began to escape out of the expansion tank through the reduction valve, the water gauge falling to zero position. We all thought that the expansion tank had burst.

June 19, 1937. 22.50. Discovered there was no water in the reserve water tank.

June 20, 1937. 14.46. Descending under the clouds near the city of Portland. The lower layer of the cloud is awful. Descent very slow in spirals.

June 20, 1937. 15.41. Petrol hand pump won't work.

June 20, 1937. 16.20. Landed at Vancouver.
Total time in the air, 63 hrs. 16 mins.

So ended a very remarkable pioneer flight.

AIRPLANE DESIGN MANUAL.

F. K. Teichmann. Sir Isaac Pitman and Sons, Ltd., London, 1940. 18/- net.

Professor Teichmann is the Assistant Professor of Aeronautical Engineering at the Daniel Guggenheim School of Aeronautics, New York University. "This book," he says in his preface, "has been written to fill what appears to the author to be a gap in aeronautical literature, an introduction to the art of aeroplane design, with the needs of the student, the young engineer, the draughtsman, and the student working on his own, especially in view, while aerodynamics, stress analysis and other aspects of aeroplane design have been covered many times, experience in dealing with senior aeronautical students has shown that such men experience considerable difficulty in co-ordinating their knowledge and efforts in approaching the difficult problem of actually beginning the design of a new machine, and carrying on the work systematically."

The aim of the book is to provide the co-ordination of the knowledge the student has acquired in different sections of his subject. It is the kind of book which is wanted in every class of engineering, the kind of book which shows a student how to apply in practice the knowledge he has acquired.

The first chapter details the general procedure in design following the study of the proposed specification of a machine. It is a general statement of the problem and the many points to be considered to obtain the preliminary lay out of the aeroplane. Chapter II deals with preliminary weight estimates. In this chapter a very full list of weights has been collected (from American sources) and this chapter records only too clearly the immense difficulty of making a weight forecast. The estimates themselves vary widely, and though each weight difference may be small, in the aggregate over the whole aeroplane, they may be very considerable. The student using this chapter should remember that United States measures are used. For example, the fuel weight is given as 6 lbs. per gallon, which would appear considerably on the low side if it were not remembered that the U.S. gallon is 0.830 of the imperial gallon. All the weights given should, indeed, be used with great caution unless the designer is prepared to find himself woefully out in his calculations. Weights are only sign posts on the way, in fact.

Chapter III deals with the general arrangement drawings, the American "three-view," and is followed by a chapter on the balance diagram. From here onwards are chapters dealing with more detail parts of the aeroplane, the pilot's cockpit, instruments, and passenger cabin. Chapter VIII considers heating and ventilation problems, and Chapter IX, sound-proofing.

Chapter X surveys the power plant. It is, of course, not concerned with engine design, but with the choice and installation of the right kind of engine in the aeroplane being designed. Design of the wing is the subject matter in Chapter XI, both aerodynamically and structurally. Here again only brief statements can be given in the space allotted, to what must be done and what must be avoided to achieve a particular object. The landing gear, tail surfaces and fuselage designs are the subject matters of the following three chapters.

The aeroplane now complete, Chapter XV outlines the procedure for calculating the longitudinal stability, and Chapter XVI those for preliminary performance calculations. The final chapter on aeroplane data sheets, begins naively, "The design of aeroplanes is largely empirical, so that it is advisable to study as many aeroplanes as possible, catalogue them under different categories, and

collect as much data as possible on performance, weights, structure, power, and all the other items that may be useful at sometime or another."

Such data will inevitably be invaluable to the budding designer, but they are only the ingredients. It takes more than the correct ingredients, mixed in the correct way, to produce a good cake. The good cook has learnt to get his results by long experience of his own as well as others. He becomes a chef of world renown if he can mix his ingredients in some slightly different way and produce a new Pêche Melba to tickle the palates of the world.

The aircraft designer is in exactly the same position. Most of his ingredients are now available, there is a wealth of experience behind him, but he will have to have more than that to produce the aeroplane which can beat its competitors so decisively as to make a real advance. He will have to possess that engineering flair which is not too common.

This book is just the kind of book which will help to co-ordinate ideas. An English book on the same lines would be invaluable.

AIRCRAFT ENGINES.

A. W. Judge, A.F.R.Ae.S. Vol. I. Chapman and Hall, London. 1940. 16/- net.

Mr. Judge in his Preface to this volume on "Aircraft Engines," says:—"The object of the present book, which is the first of two volumes on aircraft engines, is an endeavour to present the principles and results of relevant research work upon internal combustion engines, for the benefit of those entering or already engaged in aircraft engineering work. It is also written in order to fill a gap existing in aeronautical literature, between the more advanced specialist books on theory and design and the elementary descriptive ones on aircraft engines, maintenance, etc."

Let it be said at once, that the book admirably fulfils both objects. There is no doubt of the demand, in every branch of engineering, for the textbook, which is neither high-brow nor low-brow, to use a much overworked but expressive cliché.

Chapter I deals with the necessary elementary principles of thermodynamics and the three types of thermodynamic cycles of operation for internal combustion engines, the Carnot, Otto and constant pressure. The second chapter deals with the practice of these cycles as against the theory. In Chapter III, on Petrol Engine Performance, engine losses are analysed and the increase in horse-power by various expedients in the last few years shown. The outstanding progress in the Pegasus single-cylinder units, following development work in the research department of the Bristol Aeroplane Company, is shown graphically in Fig. 41 for the years 1928-1935. During those years our b.h.p./litre has risen from 18 to 37½ and the story is far from being ended. Such progress figures are an outstanding tribute to the intensive research work of the aero engine designer.

Chapter IV deals with the processes of combustion, turbulence, pre-ignition, detonation, and cylinder design, and is followed by a chapter on aircraft engine fuels and their properties. The value of a high octane number fuel is shown and it may well be that this factor may be one of the most important in obtaining the final command of the air by the Allies. An important chapter on carburettors and fuel systems follows.

In Chapter VII the all-important problem of increasing power output by super-charging is considered and is followed by a chapter on cooling.

Volume I of "Aircraft Engines" should prove of very real use to those who want an organised summary of the research work which has been carried out,

the many problems which have been wholly or partially solved, and the working principles of aero engine performance.

The book is admittedly compiled from many sources, over a hundred references are given at the end of the book, and it is hoped in future editions that there should be a greater uniformity in presentation. The designs and lettering give the impression of being hastily chosen in some instances and lettering, at least, should have been uniform. In Fig. 27 we have the word " center," in Figs. 41 and 42, " liter," but " litre " in Fig. 39. Fig. 54 gives " spark plug " and Fig. 55 " sparking plug."

THE ROYAL AERONAUTICAL SOCIETY

WITH WHICH IS INCORPORATED THE INSTITUTION OF AERONAUTICAL ENGINEERS.

MONTHLY NOTICES,

JULY, 1940.

Emergency Arrangements.

It should be made clear that although the Society has published from time to time in the Journal its emergency address and telephone number (which can be used at any time alternatively with those of the Society), the Society functions, and has functioned from the beginning of the war, from No. 4, Hamilton Place, W.1. It will continue to function from London as far as possible, even though some of the staff may have to be moved, others will continue in London itself. It is obvious that events may make things difficult and cause a certain amount of delay, and members are asked to bear these events in mind.

The emergency address is—

Brook House,
Old School Lane,
Brockham, Surrey.

Telephone: Betchworth 189.

Abstracts from Technical Press.

In future, Abstracts from the Scientific and Technical Press will be printed as a separate section of the Journal and numbered in *italic* figures. At the end of the year they will be indexed separately so that they can be found separately if required.

Election of Members.

The following members were recently elected:—

Associate Fellows.—John Sommerville Gibb (from Graduate), Denis Simpson Gunning (from Student), Frank Kendall, William James Charles Speller.

Associates.—Job Ronald Tremellen Bradford.

Students.—Roger Charles Eldridge, Peter Egbert Arthur Stevenson, Roland Graham L'Estrange Wallace.

Associate Fellowship and Associate Membership Examinations.

The following Candidates were successful at the examinations held in May, 1940:—

ASSOCIATE FELLOWSHIP.

E. N. Brailsford	Pure Mathematics. Strength of Aeronautical Materials and Structures. Design (Aircraft).
R. Clemens	Strength of Aeronautical Materials and Structures (First Place).

H. D. Conway	Pure Mathematics (First Place). Strength of Aeronautical Materials and Structures. Theory of Machines (Tie for First Place).
K. C. Goldie-Morrison ...	Applied Mathematics.
L. S. Greenland	Aircraft Materials.
S. Holman	Design (Aircraft).
D. W. Kew	Pure Mathematics. Theory of Machines (Tie for First Place). Design (Aircraft).
J. Lansdell	Aerodynamics (First Place).
A. M. H. Lewin	Pure Mathematics. Strength of Aeronautical Materials and Structures. Design (Aircraft).
W. S. Lucke	Applied Mathematics.
F. C. Moss	Pure Mathematics.
J. Nicholls	Applied Mathematics. Strength of Aeronautical Materials and Structures. Design (Aircraft).
A. R. Pitt	Strength of Aeronautical Materials and Structures. Design (Aircraft) (First Place).
G. B. Probert	Strength of Aeronautical Materials and Structures. Design (Aircraft).
F. Sahyoun	Design (Aero Engines).
A. G. Shove	Strength of Aeronautical Materials and Structures.
R. C. Sowerbutts	Aerodynamics.
W. J. Strang	Applied Mathematics (First Place).

ASSOCIATE MEMBERSHIP.

R. W. J. Horsley	Applied Mathematics.
J. A. Ross	Theory of I.C. Engines.

The Baden-Powell Memorial Prize.

The Major Baden-Powell Memorial Prize for the Student who is considered best by the Examiners in the Associate Fellowship Examinations has been awarded to Mr. H. D. Conway on the results of the May, 1940, examinations.

Elliott Memorial Prize.

The Elliott Memorial Prize has been awarded to Leading Aircraft Apprentice C. J. Pearson, who has obtained the highest marks in the General Studies Examination of the August, 1938, entry at Halton.

Correction.

Attention is drawn to page 449 of the June Journal, the seventh line from the bottom of the page, where 1.7 should read 1 : 7.

Library.

The Library will be closed on Saturday afternoons for the Summer months. Books may be borrowed by post on application. The Library will be open as usual from 9.30 to 5 o'clock from Monday to Friday and from 9.30 to 12.30 on Saturdays.

The following is a list of books missing from the Library. If any member has any of these books on his shelves which he would care to present to the Society they would be very much appreciated:—

Amundsen, R. (and Ellsworth, L.). My Polar Flight. 1925.
Cormac, P. A Treatise on Engine Balance Using Exponentials. 1923.
Edwards, J. The Differential Calculus for Beginners. 1920.
Ewing, J. A. Thermodynamics for Engineers (1st Ed., 1920). (Note: We have 2nd Ed., 1936.)
Fairham, W. Wood Turning Carpentry for Beginners. 1918.
Fairham, W. Woodwork Tools. Evans Bros. 1922.
Girard, C. Aluminium and its Alloys. 1921.
Gray, H. B., and Turner, S. Eclipse or Empire? 1916.
Hawker, J. G., and Grieve. Our Atlantic Attempt. 1919.
Guggenheim, H. F. The Seven Skies. 1930.
"H.W." Something New Out of Africa. 1934.
Hall, Barbara. Last Flight. 1935.
Halliwell, F. W. Erection and Trueing-up of Aeroplanes. 1920.
Hogben, Lancelot. Mathematics for the Million.
Hughes, A. J. Instruments for Aerial Navigation. 1924.
Jones, Bradley. Avigation. 1931.
Kermode, A. C. Mechanics of Flight (1937 Ed.). (We have 1932 and 1934 Editions.)
Needham, Latimer. Sailplanes. (Two copies.)

Additions to Library.

U.F. 3.—Ministère de l'Air: Publications Scientifiques et Techniques:—

No. 160. Etude des Capsules Anéroides. Fernand Charron. Frs. 20.

No. 161. Etude des Produits Résiduels des Huiles de Graissage. Mlle. G. Cauquil and Raymond Calas. Frs. 12.

UF. 4.—Ministère de l'Air: Bulletins Scientifiques et Techniques:—

No. 90. Recherches sur le Classement des Carburants à Valeur Antidétonante élevée. Henry Moynot. Frs. 12.

No. 91. Recherches Physiochimiques sur les Carburants et Lubrifiants. M. Aubert and Jean Villey. Frs. 30.

UH. 3.—Atti di Guidonia. (Editoriale Aeronautica, Rome):—

No. 14. Contributo alla Teoria delle Strutture Iperstatiche. Un Nuovo e Generale Procedimento di Calcolo. Luigi Broglio.

No. 16. Contributo alla Teoria dei Solidi cavi a Parete sottile. Introduzione di un nuovo e generale Procedimento di Calcolo per le Ali a Cassone. (I Parte.)

No. 23. La Galleria Verticale per le Esperienze di Avvitamento. Dr. A. Vannucci and Dr. V. Ciampolini.

No. 24. Una Bilancia Aerodinamica a 6 Componenti. Dr. Antonio Eula.

UL. 3.—Institute of Physical and Chemical Research, Tokyo:
Scientific Papers, Nos. 961-964. Various Authors.

UU.c.—National Advisory Committee for Aeronautics: Technical Memoranda:—

No. 939. The Torsion of Box Beams with One Side Lacking. E. Cambilargiu. (From Luftfahrtforschung, Aug., 1939.)

No. 940. The Lead Susceptibility of Fuels and its Dependence on the Chemical Composition. O. Widmaier. (From A.T.Z., Feb. 10, 1940.)

V. 8.—Royal Society of Edinburgh:—
Proceedings, Vol. LIX, Part III (1938-39), and Vol. LX, Part I (1939-40).

D.b.53/PD.1/17.—European Air Transport on the Eve of War. By J. Parker Van Zandt. Norwich University, Vermont. 1940.

EE.j.22/PEE.3.c.6.—The Development of the Monosleeve Valve for Aero Engines. By A. H. R. Fedden. Inst. of Automobile Engineers. 1939.

G.a.49.—Metallurgical Abstracts, Vol. 6, 1939. Institute of Metals. 1939.

G.b.29.—Recommended Materials for Marine Engineering. Mond Nickel Co. 1940.

G.e.B.17/PG.3.b.8.—The Resistance of Copper to Soil Corrosion. H. G. Taylor. Copper Development Association. 1940.

G.d.7.—The Anodic Oxidation of Aluminium and its Alloys. By Dr. A. Jenny. Chas. Griffin and Co. 1940. 16/-.

G.e.A.53/PG.3.a.13.—The Use of Refrigeration for Delaying the Age-Hardening of Duralumin-Type Alloys, with Special Reference to the Production of Large Pressings for Aircraft. By J. C. Arrowsmith and K. J. B. Wolfe. Inst. of Metals (Extract, Vol. 66, Part 5). 1940.

L.j.75.—Airman's World. By Peter Supf. George Routledge. 1933. 10/6.

N.a.62.—Science since 1500. By H. T. Pledge. H.M.S.O. 1939 (reprinted 1940). 7/6.

Q.b.57.—Carnegie United Kingdom Trust. 26th Annual Report.

S.b.79.—A History of the Air Ministry. By C. G. Grey. Geo. Allen and Unwin, Ltd. 1940. 10/6.

J. Laurence Pritchard, *Secretary and Editor.*

The 649th Lecture read before the Royal Aeronautical Society since its foundation on January 12th, 1866.

PROCEEDINGS.

A meeting of the Royal Aeronautical Society was held in the Lecture Theatre of the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, London, W.C.2, on Friday, April 12th, 1940, when a paper on "The History and Progress of Refuelling in Flight," by Sir Alan Cobham, K.B.E., A.F.C., Hon. F.R.Ae.S., and Mr. Marcus Langley, F.R.Ae.S., was read and discussed.

In the chair: Lieut.-Colonel J. T. C. Moore-Brabazon, M.P. (Past-President).

The CHAIRMAN: He welcomed Mr. Langley as an old friend and Member of Council of the Society, who had done much good work on the technical side in the development of the de Havilland School. Sir Alan Cobham was a national figure, who had probably done more than anybody else to indicate the possibilities of aviation relative to our Empire; he was a well-known and popular figure, and his honours were well deserved.

Refuelling, continued the Chairman, introduced great technical possibilities, and to him it was always interesting, because at the time he had first flown it was considered very important not to have any petrol at all on the machine if one could help it; half a gallon of petrol was considered ample, to hop off with. Nowadays the achievement of optimum wing loadings and the ability to carry heavy loads were all-important for long range machines of both military and civil types, and refuelling in flight gave them great advantages in connection with the operation of such machines.

THE HISTORY AND PROGRESS OF REFUELLING IN FLIGHT.

By Sir ALAN COBHAM, K.B.E., A.F.C., Hon. F.R.Ae.S., and
Mr. MARCUS LANGLEY, F.R.Ae.S.

My experimental work in flight refuelling goes back over a period of ten years, when I became interested in its possibilities as a means of removing the hazard of a heavily loaded take-off. My idea was that an aircraft should have a normal and safe take-off, and that when it was comfortably in the air, it should receive its load of fuel, thus being given both an extended range and an increased pay-load.

In 1932, initial experiments were carried out on two D.H. 9's, and early in 1933, we continued experiments with a D.H.9 and a Handley Page W.10 transport machine.

About this time, the Courier was designed for the purpose of a non-stop flight to Australia, by means of flight refuelling. The Courier was a single-engined, low wing monoplane, fitted with an Armstrong-Siddeley Lynx engine. The maximum permissible weight for unassisted take-off was just over 3,700 lb., but the main structural factors allowed an all-up weight of over 5,050 lb., when in the air. Thus the weight was increased by over 35 per cent.

Eventually, with the collaboration of the Air Ministry, a flight to India was arranged, during which the Courier was to be refuelled by Service aircraft temporarily converted for the purpose. At this stage in our development it was the practice of the receiving aircraft to formate on the tanker. Because all the formation was to be done by the Courier written instructions were sufficiently explicit to enable Service aircraft to meet it at stated points, make contact and transfer the fuel without any previous practice on their part. The flight would

undoubtedly have been a success, but unfortunately a throttle broke after the machine had been refuelled at Malta, and a forced landing had to be made on the island.

Considerable data were collected in 1933 and 1934. Systems were developed and equipment made, and in 1935 I came to the conclusion that the correct method for refuelling in flight was briefly as follows:—

The whole job of refuelling should be in the hands of an expert tanker crew and no special skill should be demanded of the pilot of the receiving aircraft.

The tanker (giver) should formate on the liner or bomber (receiver) and the hose should pass from the nose of the tanker to the tail extremity of the receiver's fuselage. Furthermore, the tanker should formate behind, above, and to one side of the receiving aircraft. In such conditions, because the hose and the hauling and contacting lines passed over no part of either aircraft, but were behind the receiver and below the tanker, they would not touch or become entangled in any part of the machines if they were to break. We have adhered to that principle ever since.

In 1935 Imperial Airways became interested in Flight Refuelling, Limited. The Air Ministry still continued to support our development work and provided two Virginias for a further stage of experiment.

A new arrangement came into full operation in January, 1936, and since that date the Company has been fully employed, without a break, on the continuous development of flight refuelling. Complete records of every flight and experiment have been carefully kept, and now we have sufficient data and experience of successful achievement to state that the process is no longer an experiment, but a practice which can be put into everyday use.

In the summer of 1936, very full demonstrations were given to the Directors of Imperial Airways, showing the progress we had made with the two Virginia Aircraft. These indicated that if further progress were to be made, we must have faster and more powerful machines.

Our next stage of development came with the A.W. 23 transport machine acting as a tanker; demonstrations were given at Farnborough in the summer of 1937, when contacts were made with the Handley Page 51. These were useful in showing our type of contact and demonstrating our hauling down windlass, hose, nozzle, and couplings.

Very important trials were carried out in January, 1938, at Hamble, when a programme of experimental flights was conducted in all-weather conditions, some of which were extremely bad. The tanker machine was the A.W. 23; the liner receiver was an Empire Flying Boat. Many useful data were collected as we carried out refuelling in storm, fog, rain and low cloud. We came to the conclusion that, generally speaking, flight refuelling can be carried out whenever it is possible to operate air transport.

In the early spring of 1938, in order to investigate all systems of flight refuelling, a sequence of trials was carried out at Ford Aerodrome, with a Vickers 27 and an Overstrand.

In June, 1938, we conducted a daily sequence of flight refuelling demonstrations, which were operated at precisely 11 o'clock each morning. Interspersed with this sequence of trials, we carried out an extensive programme of varied experimental work. These proved that refuelling in flight could be used for a daily schedule service, under all conditions.

The Atlantic Service of 1939.

By then we were already working on the problems of the Atlantic Service, which was to start in June, 1939. A number of specially strengthened Empire Boats were in hand. These had been designed for refuelling gear and were to take-off at 46,000 lb., the weight being increased to 53,000 lb. when in flight. Higher power was provided by Perseus engines instead of the Pegasus engines of the original Empire Boats.

The purpose of this service was to continue the development work on the Atlantic route which had been begun in the earlier crossings of the Cambria and the Mercury, and the boats were to be refuelled because this allowed them to carry a greater pay-load than would otherwise be possible, and it was to serve as a full-scale experiment in refuelling a scheduled service. There was no thought in anybody's mind that the Empire Boats were particularly suitable for the job, or that they would show the maximum advantages which might be gained from refuelling.

If the mechanism of the process functioned sufficiently well and a certain additional pay-load was made available, then the purpose of the 1939 service would be fulfilled. The experience gained from it could then be applied to future developments, any snags which were found in the equipment could be overcome, and more suitable aircraft could be designed to take full advantage of the process.

Handley Page Harrow bombers were converted into tankers having a cargo capacity of 800-900 gallons and the first two of these were shipped out to Newfoundland in charge of Flight Lieut. Johnson during April. They reached Newfoundland Airport and were complete with crews and all equipment by the third week in May. This airport is very large and will be well equipped when completed, but it is situated some 40 miles away from the flying boat base at Botwood, the intervening country being wild and hilly with inadequate transport.

In the meantime the boat crews were trained at Ford and given some four hours' flying experience of the process. The first officer of each boat was to be in charge of the refuelling operation, and he was to be assisted by the second wireless operator. The captain, or pilot, of the flying boat required no more than ten minutes' verbal instruction as he had only to fly a straight and level course during the operation. In actual practice the automatic pilot had charge of the flying boat on more than one occasion during the whole time that fuel was passing.

The tanker for the Irish base at Foynes which had been used for the training flights was flown there in time for the opening of the service. It was in charge of Flight Lieut. Tyson.

The service did not actually begin until the departure of Caribou on its first west bound flight on August 5th, 1939, and ended with the arrival of the last east bound machine, the Cabot, on October 1st, 1939. Sixteen crossings were made within this period, there being eight each way at weekly intervals.

The refuelling operation was successfully performed on fifteen of the sixteen occasions. On the one occasion when refuelling was not used it was unnecessary because there was a very strong westerly wind, with the aid of which Captain Kelly Rogers was able to bring the Cabot across from Newfoundland in some ten hours, and on arrival at Foynes he still had sufficient petrol to get home to Southampton. Unfortunately such winds cannot be arranged to order.

As might be expected, there were some small mechanical defects found and some mistakes made in the operation of the earlier flights, but these were never sufficient to prevent the refuelling process being successfully completed without undue waste of time. It is significant that the last ten flights were completely successful in every detail, and that there were no hitches of any sort.

The average time between making contact and turning on the petrol was five minutes, and the limits were three minutes and seven minutes for this part of the process. The passing of the fuel was almost consistently seven to eight minutes for 800 gallons.

(1) Lessons from the Atlantic Service.

a. The Tanker.

The conclusions drawn from the Atlantic Service are as follows:—

1. The refuelling equipment was adequate and requires no major modification. There are minor modifications to be made and labour would be

saved if the units were mechanised. This is now being done. The addition of a flow meter is very desirable.

2. The tankers require adequate wireless equipment. In future they must be fitted with homing and blind landing sets of types to suit the bases from which they are working.

3. The Harrows were suitable aircraft for tanking the Empire Boats, but for larger and faster air liners it would be necessary to have more advanced tankers. It is not yet necessary to consider the building of special tankers since certain obsolete or obsolescent aircraft would, for many years, be available. For example, when the Empire Boats are superseded as first line aircraft they would make admirable tankers, of perhaps 2,000 gallons capacity. Amongst newer types the D.H. Albatross or Frobisher class would be very suitable for refuelling up to 1,000 or 1,200 gallons at a time. The operating and "formating" speed of the tanker (with hose pipe down) must be such as to allow an adequate margin for formating above the stalling speed of the receiving aircraft. Thus, if the latter is to be loaded to 60 lb. per sq. ft., then the tanker must be able to refuel at not less than 150 m.p.h. This means that the tanker should have a cruising speed, under normal conditions, approaching 200 m.p.h. The engines of the tanker need not be supercharged to a great height. The Pegasus XX engines of the Harrow give maximum cruising power at a height of 11,000 ft., whereas the operations during the 1939 season were never done at more than 3,000 ft. and usually at 1,000 ft. Allowing for bad weather near the ground, and giving the tanker the ability to do its job over the worst likely conditions, it would seem reasonable to compromise on engines having a supercharged height of about 6,000 ft. This would still allow them to operate at a greater height on the rare occasions when the weather forced them up.

b. The Refuelled Air Liner.

The S.30 flying boats, used to operate the 1939 summer service, were not capable of taking full advantage of refuelling. They were underpowered and of insufficient structural strength to carry any load greater than 53,000 lb. Nevertheless, the margin between that load and the load which they could actually take off the water made a considerable difference to their revenue earning capacity. They were definitely worth operating, but future types can now be designed to show an enormous advantage over any non-refuelled machine.

The next generation of air liners which is to operate long range services should be designed from the start to take advantage of refuelling. The machine must be of clean outline and of sufficient structural strength to allow of its carrying a load equivalent to 50-60 lb. per sq. ft. of wing area when in free flight.

The hull bottom (or the undercarriage, if it is a land plane) need not be stronger than is necessary to take 30-35 lb. per sq. ft. when taking-off or landing. This will give a considerable saving in structure weight by comparison with the corresponding aeroplane designed to take-off at its full all-up weight.

The take-off power should be such as to give a power loading of 7-10 lb. per b.h.p. at take-off weight. The cruising power loading will then be of the order of 20 lb. per b.h.p. at the refuelled all-up weight.

Such an aeroplane should be capable of flying non-stop from England to New York with a large pay load.

The actual size of this machine would have to be correlated with that of the tanker, the tankage capacity of the latter being equivalent to the difference between the 30-35 lb. per sq. ft. take-off loading of the former, and its refuelled loading of 50-60 lb. per sq. ft. This size would be decided by the capacity of the tanker available. These figures are justified in Section (3) of the paper, which deals with the theoretical considerations of high wing loading.

c. Refuelling Bases.

It scarcely needs stating that the more work which can be given to a particular refuelling base the cheaper will be the service. The Irish and Newfoundland bases had only to handle one service per week each for eight weeks.

They could with ease have handled ten or more services per week without any additional overhead charges, and with very little additional operating expense. Even ten services would only have demanded ten hours' weekly flying by the operating staff. This would have been very well within their capacity.

When refuelling becomes generally accepted, the refuelling bases must be carefully chosen. Thus, for example, Alexandria would be an admirable position, since it could handle both inward and outward bound aircraft on both the South African and Far Eastern Services. One type of tanker could be used there for either land planes or flying boats since the seaplane bases and aerodrome are adjacent.

It is difficult to imagine an overworked base, and every additional service which it handles reduces the cost per gallon of " refuelled " petrol.

It must be remembered that a refuelling base is mobile and can very quickly move with the seasons of the year, and with the political situation. Unlike a catapult, an extra large aerodrome with special runways, or a crane, the refuelling base requires no fixed equipment or anchored capital.

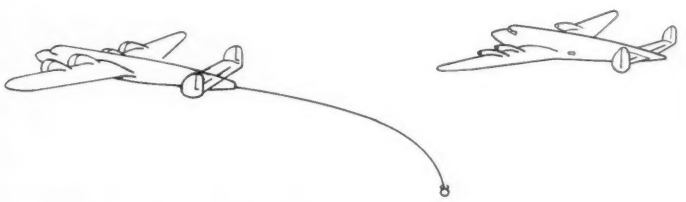
The Irish and Newfoundland bases served for the 1939 summer service, but this is one of the most difficult routes in the world to operate. We began with this route, and we are confident that if we can successfully operate from Newfoundland and the Shannon we shall not experience greater difficulties on the civil air routes of the world than we have already met with in giving service on this particular route for the North Atlantic.

(2) The Process of Refuelling in Flight.

Description of the Operation.

Several methods of making contact may be used alternatively, of which two are described below. These are:—

(*a*) The Ejector Method.
(*b*) Taking off in Contact.



THE LINER TRAILS ITS SINKER WEIGHT & HAULING LINE

FIG.1.

The Ejector Method may be described as follows:—

After taking-off, the receiver trails its 10 cwt. steel hauling line and sinker weight through the receiver coupling, situated at the extremity of the tail. The tanker flies up behind, to one side and slightly below the receiving aircraft (see Fig. 1). From an opening in the side of its fuselage it fires a projectile

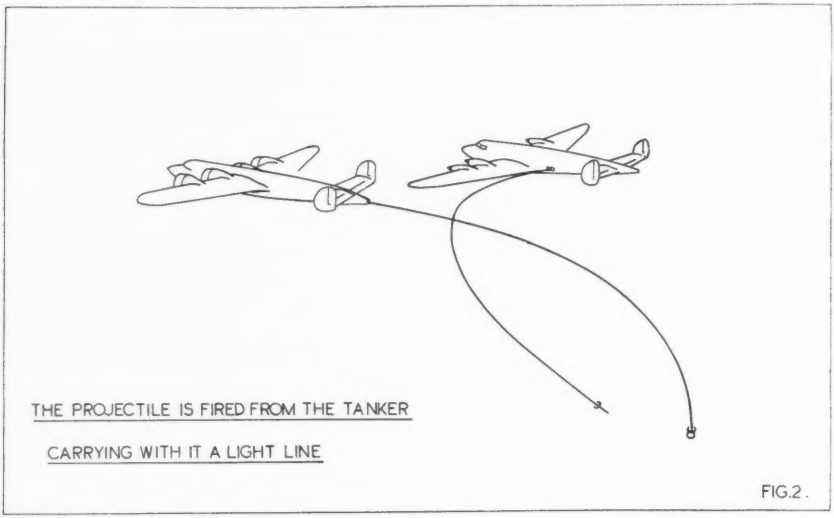


FIG.2.

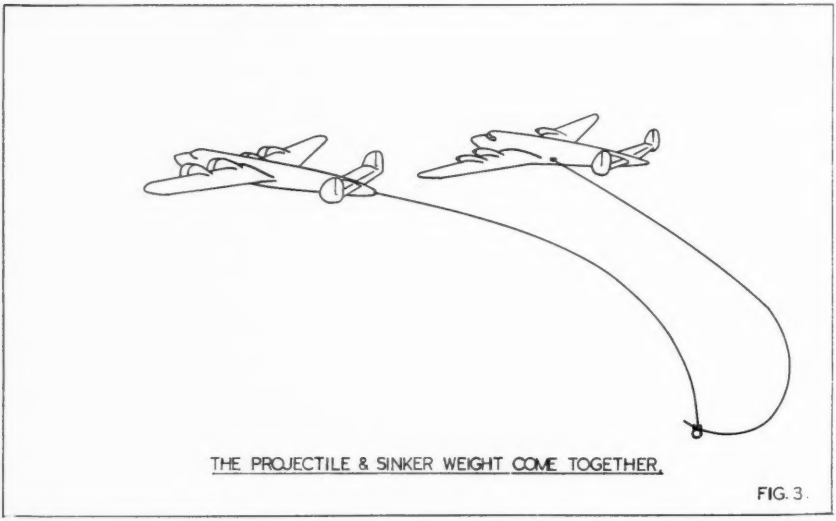
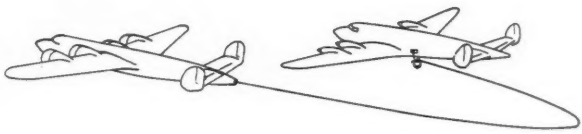


FIG. 3.

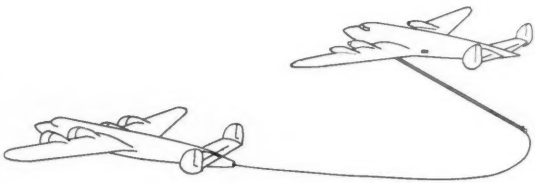
and line from a B.S.A. line throwing gun of the type used for life saving at sea. The thrown line, which is a 5 cwt. flexible steel cable, when spent, drifts back against the quarter elliptical arc of the trailed hauling line (see Fig. 2). It then slides down the line and engages with the grapnel on the sinker weight (see Fig. 3).

The sinker is wound up into the hatchway on the underside of the nose of the tanker (see Fig. 4), and after it has been detached from the hauling line by means of a bayonet fitting, the line is plugged into the nozzle of the hose pipe. The hose pipe is now lowered away, the tanker in the mean-



THE SINKER WEIGHT IS DRAWN BACK INTO THE UNDERSIDE OF THE TANKER & THE HAULING LINE ATTACHED TO THE NOZZLE OF THE HOSE PIPE

FIG.4.



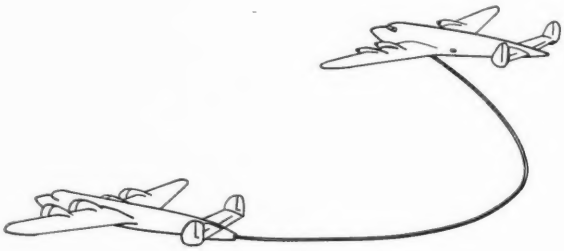
WHILE THE TANKER CLIMBS TO THE UPPER POSITION THE HOSE IS LOWERED AWAY & THE NOZZLE HAULED INTO THE RECEPTION COUPLING

FIG.5.

time having climbed into a position above, behind, and to one side of the receiver (see Fig. 5). As the hose pipe is lowered, the receiver hauls the nozzle into the receiver coupling in its tail (see Fig. 6) and the hose and pipe lines are flushed with nitrogen. The refuelling operation may then begin.

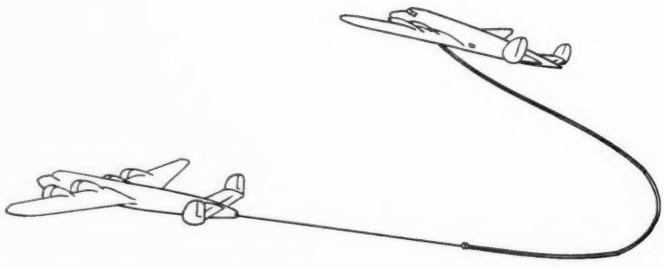
When all the fuel has flowed through, the hose and pipe lines are again flushed with nitrogen.

As the nozzle breaks away from the coupling a methyl bromide bottle is automatically opened. This completely floods the coupling with a fire preventative and removes all risk if a static discharge occurs at that point. As the nozzle



THE HOSE PIPE BEING IN POSITION THE FUEL IS ALLOWED TO PASS

FIG.6.



THE OPERATION COMPLETED THE LINER RELEASES THE NOZZLE & PROCEEDS ON ITS COURSE.

THE TANKER TURNS FOR HOME, WINDING IN THE HOSE AS IT GOES.

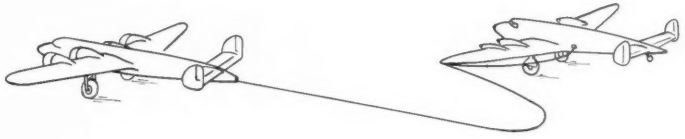
THE WEAK LINK IN THE HAULING LINE BREAKS IN MID-AIR AS THE AIRCRAFT PART. FIG.7.

leaves the coupling it carries with it the hauling line and then a false hauling line, until some 300 ft. have run off the windlass. (This length is clearly marked on the hauling line by a change in the coloured covering.) When the two aircraft move away from each other as shown in Fig. 7, a weak link in the line is broken

in mid-air, some 75 ft. from each aircraft, and any spark which might occur at the breaking of contact is away from all danger of fire or explosive mixture.

This method of making contact in the air has several advantages over those previously used. It is quick in that the aircraft are flying on parallel courses at the distance apart used throughout the whole refuelling process. The tanker has only to climb into an upper position after the grapnels have engaged. It has neither to cross the path of the receiver nor follow up close behind it before turning out. Provided that the aircraft are in their correct relative positions, within fairly wide limits, the lines must always engage, every factor being constant for a given air speed. The method can therefore be used at night or at any other time when it is impossible to see the lines themselves. This method requires no directional manœuvring on the part of either aircraft.

Taking off in contact is an alternative method which has further advantages. The two aircraft, receiver and tanker, take off simultaneously, connected by a light line, running from the wing tip of the tanker to the reception coupling of the



TAKING OFF IN CONTACT

FIG.8.

receiver (see Fig. 8). When in the air, this light line is released from the wing tip and is used to pull the main hauling line across from receiver to tanker. This in turn is used to haul the hose pipe across exactly as shown in Fig. 5 for the Ejector Method.

The transfer of the hauling line across to the tanker can begin the moment the aircraft have left the ground, and in this way as much as $1\frac{1}{2}$ minutes may be saved in the actual operation of refuelling, and 3 minutes in the total flying time of the tanker per operation.

Before two very dissimilar aircraft were taken off in contact, their relative unstick distances, speeds, and initial rates of climb would have to be very carefully considered. The comparison might best be made by recording the actual take-off of each at its correct weight by means of a panoramic cinema camera.* The photographic negatives are then superimposed and a direct comparison is at once presented. In actual practice, we have found that taking off in contact is a very

* A special camera for this purpose has been developed and is described in " The de Havilland Gazette " No. 23, March, 1939, and in the Journal of the Royal Aeronautical Society, June, 1939.

simple procedure. The connecting line " flies " within a second of opening up, and the apparatus we have designed proved reliable.

(3) Theoretical Considerations: The Effects of Large Increments in Wing and Power Loadings on the Performance of Aircraft.

Preamble.

Throughout the history of aircraft design there has been a constant tendency to increase wing loadings. In pre-war days the limit was less than 10 lb. per sq. ft., but this had risen steadily to 20 lb. per sq. ft. a few years ago, and now to 30 lb. per sq. ft. or more.

In return for this increase in loading, designers have been able to give ever-increasing speed, but they have paid the price in the raising of landing speeds and the length of take-off runs. To prevent deterioration at the low end of the speed range, they have provided flaps, controllable pitch airscrews, ground boosting of engines, tricycle undercarriages, and so forth.

Is there a limit to the increase in wing loading? In the past it has always been limited by ground conditions; if that restriction were removed, how far could one go?

In 1907, Lanchester (Ref. 1) showed that the total resistance of an aeroplane is least when the " direct resistance " and the " aerodynamic resistance " are equal to one another. More recently, in 1937-38, it has been proved that this very early conception was correct, but that the optimum wing loading might be so high that no aeroplane could take it off the ground (Ref. 2).

Vessey and Belart, ignoring the practical restrictions of take-off climb and landing, have considered what would happen if the wing area of an aeroplane were gradually reduced, leaving the weight and power constant. Vessey (Ref. 2) found the optimum wing loading of a typical modern monoplane to be 62 lb. per sq. ft. Up to that loading there was a gradual improvement in speed from 239 m.p.h. to 255 m.p.h., but this was followed by a falling off in speed as the induced drag (Lanchester's " aerodynamic resistance ") became greater than the profile drag of the wing (Lanchester's " direct resistance ").

Belart (Ref. 3) showed that the Douglas D.C.2 would benefit 6 per cent. in speed by an increase in the wing loading from 19.8 lb. per sq. ft. to 49.6 lb. per sq. ft. In the Heinkel 70 there would be a gain of 11.15 per cent. in speed, following an increase in wing loading from 18.5 lb. per sq. ft. to 72 lb. per sq. ft.

At such loadings, of course, no aeroplane could leave the ground. Nor is the conception of a gradually shrinking wing other than a mathematical method of proving a principle.

Methods of Assisting Take-off.

Various methods of assisting heavily-loaded aeroplanes into the air have been suggested, and used at different times. An examination of the equation for the accelerating force during the take-off suggests the following classification of these methods:—

1. Improvement of Thrust.

- (*a*) Controllable pitch airscrews.
- (*b*) Ground boosting of the power plant, including the use of high octane fuel.
- (*c*) Catapulting, accelerators, inclined runways, etc.
- (*d*) Mayo Composite Aircraft.
- (*e*) Rockets.
- (*f*) Engine-driven bogies.

2. Reduction of Drag.

- (*a*) Reduction of coefficient of friction by means of bogie on rails, concrete runways, etc.

3. Improvement of Lift.

(*a*) Flaps of various designs, including mechanical variation of wing camber.
(*b*) Makhonine's span-wise variation of area.
(*c*) Use of slipstream and angle of thrust line relative to wing, according to the Crouch-Bolas patents.
(*d*) Mayo Composite Aircraft.

4. Reduction of Weight.

(*a*) Addition of fuel, subsequent to the take-off, by the methods of Flight Refuelling Limited.

Several of these methods are to be found combined in the design of modern transport and military aircraft. Thus it is now usual to fit a modern air liner with controllable pitch airscrews, ground boosted power plants, and low drag flaps, to gain some advantage from the slipstream in improved lift, and to operate it from aerodromes having concrete runways. It is only by these methods that loadings as high as those now used are possible. But these loadings are far from being the optimum loadings in flight.

Certain of the methods are not suitable for military aircraft, particularly those which imply the use of specially prepared aerodromes. Others are not particularly suitable for passenger purposes. For example, the acceleration of a catapult used for a passenger transport would have to be so low that its cost, weight and dimensions would be prohibitive.

The catapult on the "Ile de France," which was designed to launch an aeroplane of only 9,000 lb. at 112 m.p.h., weighed 60 tons, whilst those on the "Bremen" and "Europa," which were of similar capacity to that of the "Ile de France," are quoted as weighing 260 tons, exclusive of understructure and compressor installation (Ref. 4).

Squadron Leader R. L. R. Atcherley has given (Ref. 5) an estimated figure of £70,000 for a ground accelerator to launch an 80,000 lb. aircraft. If mounted on a ship, its cost would be approximately £100,000.

In operating a service from Southampton to New York it would be necessary, of course, to maintain a catapult permanently at each end. Thus, apart from the hazard of catapulting, the system lacks the mobility provided by refuelling, in which the tankers can be quickly and easily moved to suit meteorological and political contingencies.

Catapults would have a very limited application in military operations. The kind of catapult which would be necessary to get a large bomber off the ground could not be made mobile. To put a complete squadron into the air simultaneously would need a number of such catapults at the aerodrome, and the aircraft designed for use on these catapults would have a very restricted load if they had to be operated from aerodromes elsewhere. If, for example, the scene of war shifted to some hitherto neutral country, it might be months before catapult-launched aircraft could be used from there, and then only at great expense.

Hazards of a Heavily-Loaded Take-off.

Another classification of the above methods would be one dividing them into:—

(*a*) Those which are substantially safe.
(*b*) Those which introduce a hazard.

The exigencies of military services may demand the taking of certain risks which improve efficiency, but such action is rarely justified in civil aviation. Thus one must recognise as such those methods which assist an aeroplane into the air, but leave it in a dangerous condition should there be a sudden stoppage of one of the engines.

Although engine reliability has improved enormously in late years, several distressing accidents have recently resulted from power plant failure. The con-

dition of a heavily-loaded aeroplane, having a low rate of climb, at the moment of withdrawing the assistance of ground boosting, catapults, runways, and so forth, is extremely hazardous. The failure of only one power unit will encroach upon its power reserve and reduce its rate of climb to a negligible, or even negative, quantity. The risk of such a failure varies in exact proportion to the number of power units used, although the resulting embarrassment is correspondingly less.

Power Loading.

It is obvious that low power loadings (*i.e.*, high-powered engines in relation to the weight) are not profitable, and this fact has been demonstrated graphically (Ref. 6), but low power loadings have been forced upon aircraft operators by take-off and climb considerations. The ideal arrangement is that which gives a low power loading for the take-off *and climb to a safe operating height*, combined with a high and profitable power loading, during the period of level " cruising power " flight. This ideal is, we submit, at least approached by the addition of the greater part of the fuel load at a safe altitude.

Aerodrome Sizes.

Suggestions have been made that aircraft efficiencies would improve if longer take-off runs were permitted. This implies two things.

Firstly, that aerodrome sizes would have to be increased, and secondly, that the I.C.A.N. regulations governing maximum permissible take-off distance would have to be relaxed.

Regarding an increase in the sizes of aerodromes, one must face the fact that already, owing to their size, they are having to be put too far from the centres of population. Further, we have already sterilised tens of thousands of acres of the best agricultural land by turning it into aerodromes. The cost, both in actual money and also in terms of national self-sufficiency of food supplies, is already too high.

Aerodrome area increases as the square of the runway length, which in turn varies as more than the square of the wing loading, power remaining constant. The surrounding sterilised area, free from obstructions such as would hazard the heavily-loaded machine in its initial climb, is similarly a high function of the wing loading. Thus, as is shown on a later page, an aeroplane having a take-off run of about 300 yards at 30 lb. per sq. ft. wing loading would require over 500 yards at 40 lb. per sq. ft., over 800 yards at 50 lb. per sq. ft., and if a normal take-off were required at 60 lb. per sq. ft., the distance would be nearly 1,300 yards. Doubling the wing loading increases the length of run to more than four times its original length, and the area of a square aerodrome to give this run in any direction to more than sixteen times. The sterilised area around the aerodrome must be even greater with the heavily-loaded machine owing to its very flat angle of climb. A contour in the close vicinity would be impossible.

Regarding the I.C.A.N. regulations, one must be extremely careful before agreeing that any relaxation is desirable. An increase in the permissible " unstick " distance would probably encourage the use of many aeroplanes having highly dangerous qualities, should one of their engines fail after the machine has left the ground.

Whilst some relaxation has already been given (Ref. 7), it would be highly undesirable to apply it to passenger-carrying aeroplanes, even though it includes a requirement to cover the maintenance of height after the failure of one or more engines. The granting of a Certificate of Airworthiness to long-range aircraft taking advantage of this relaxation officially limits their use to certain airports.

Military aerodromes, and particularly those used for heavy bombers, would in time of war be one of the most important and vulnerable targets for attack. This is demonstrated in the frequent attacks on such aerodromes in the German attack

on Poland, and in both the Spanish Civil War and the conflict between Japan and China. In such conditions, runways might be seriously damaged and a very restricted area left for take-off and landing. This in turn would seriously restrict the load which bombing aircraft could take off the ground.

Under conditions of field warfare where prepared aerodromes of large size are unlikely to be found, the effectiveness of military aircraft might be seriously reduced.

In both these examples, refuelling offers a completely mobile method of overcoming the effects of enemy action or natural conditions, or alternatively offers a big increase in useful load.

Refuelling in Flight.

After a thoughtful consideration of all these points, it would seem that the most efficient method of assisting a heavily-loaded long-range aeroplane into the air is to make it a lightly-loaded aeroplane until it has reached a safe operating height. The fuel which gives it the long range and earning capacity is then added from a flying tanker, and the machine proceeds on its course. Should engine trouble develop, a suitable amount of weight in the form of petrol is jettisoned, and safety is preserved.

Non-Stop Refuelling.

Although the greater part of this paper is devoted to refuelling in flight as a means of assisting the take-off and initial climb of heavily-loaded aircraft, there is another application of the process which may prove to be of great commercial value. We refer to the refuelling of an aircraft at some intermediate point along its route. An example of its value may be found in the North Atlantic route by way of the Azores. The Azores having so little commercial or tourist trade, an aircraft is not justified in making a landing there, and the only justification for such a landing is to refuel. The harbour facilities for flying boats are poor, and boats which have alighted there have sometimes had to wait days for suitable weather for a safe take-off. For land aircraft the position is even worse, and no aerodrome of any size is possible.

A tanker having a relatively light loading could, however, operate from the Azores, particularly if the pilot were used to the place. It would, therefore, be possible to establish a flight refuelling depot there, and to give fuel to transport aircraft which would pass over, but not stop.

Another example of this sort might be found in operating a certain route with very heavy land planes capable only of taking off from concrete runways. At one essential refuelling point, the only one within hundreds of miles, is an aerodrome which is entirely unsuitable for a heavy machine, owing to its limited dimensions which cannot be increased. A tanker, half the weight of the transport machine, can, however, work from this aerodrome and refuel the other in flight as it passes over. The only requirement is adequate wireless communication, whereby the transport can give notice of its approach, its estimated time of arrival, and its requirements in petrol. The tanker must be equipped with D.F. gear, so that the two aircraft may " home " on each other if visibility is poor. We understand that this " homing " in flight has actually been tried, and that it works successfully.

Another example of such non-stop refuelling may be found in the case of an aircraft running short of fuel towards the end of a long journey. At present, the tendency is to carry a large excess of fuel against the contingency of a continuous head wind. Only on a few occasions is this excess of fuel justified, but if it were not there, the results would be catastrophic. If, however, the aircraft were equipped for refuelling in flight, it could cut down its reserve fuel (to the great benefit of its pay load) and rely on a tanker coming to meet it on the few occasions when the excess were necessary.

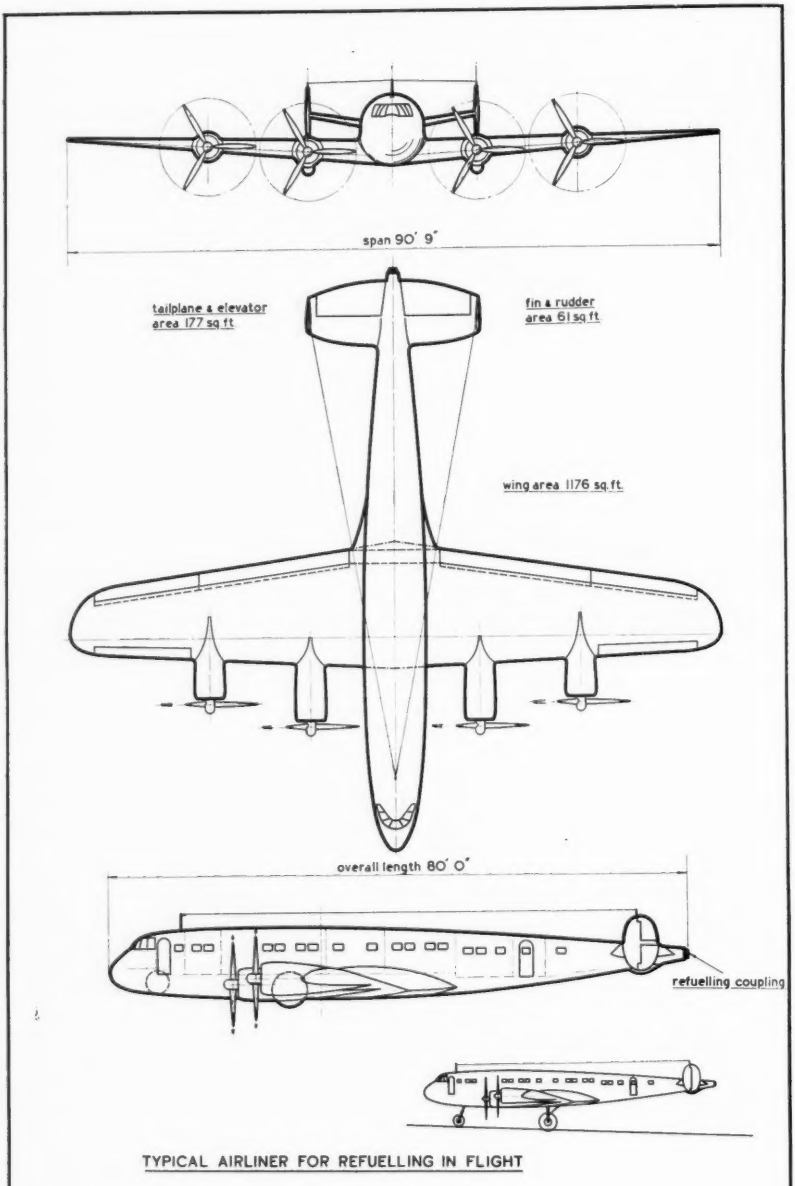

span 90' 9"
tailplane & elevator
area 177 sq ft
fin & rudder
area 61 sq ft
wing area 1176 sq ft
overall length 80' 0"
refuelling coupling
TYPICAL AIRLINER FOR REFUELLING IN FLIGHT
4 Bristol Hercules IV (civil) sleeve valve engines
Flight Refuelling Ltd.
Ford Aerodrome
Yapton. Sussex.
Drg. No. D 1345 4. 8. 38.

FIG. 9.

Two hundred and fifty pounds of refuelling equipment is only a fraction of the weight of two hundred and fifty gallons of fuel, and yet two hundred and fifty gallons is frequently left behind in the tanks of trans-Atlantic aircraft at the end of their crossings, it having been carried across at the expense of nearly a ton of pay load.

If it is possible on any world air routes to provide a tanker service midway between two destinations, where landing facilities for the air liner or flying boat are impractical, then surely it is worth while to refuel in the air and take on the petrol required, instead of carrying petrol for the entire journey, thus reducing the available pay load.

Typical Example of a Modern Air Liner.

1. Description of the Aeroplane Used as an Example.

After a comparison of some of the most modern air liners at present coming into service, the project shown in Fig. 9 was drawn.

It will be seen that this is a four-engined monoplane, having a tricycle undercarriage and twin rudders, these working in the slipstreams of the inner engines. The design is completely conventional, since we wished to avoid side-tracking the main issue with discussion on any unconventional features.

In order not to weight the argument for flight refuelling, this aeroplane has been given everything to favour a normal take-off. It has a low-power loading, constant-speed airscrews, low-drag flaps of the Handley Page slotted type, combined with ailerons which can be set down to a neutral angle of 20 degrees.

The tricycle undercarriage is thought by its protagonists to shorten the take-off and landing runs. Regarding the engines used, the machine is shown in Fig. 9 as it would appear if fitted with air-cooled sleeve valve engines of the Bristol " Hercules " type.

The engines are rated to give their maximum level power at 4,500 ft., whilst the cruising conditions are studied at an altitude of 5,000 ft.

2. Procedure.

Starting from a basic wing loading of 30 lb. per sq. ft. and a power loading of 6.4 lb. per h.p. (at take-off power) the all-up weight has been increased in stages to give wing loadings of 40, 50 and 60 lb. per sq. ft. *This corresponds to the process of refuelling in flight, all dimensions and the engine power remaining constant.*

It is, of course, different from the purely theoretical conceptions of Vessey and Belart, in which the wing was assumed to shrink. Thus, as the wing loading is increased, the power and span loadings alter, as shown in the following table:—

Wing Loading.	Power Loading.	Span Loading.	All-up Weight.
30 lb./sq. ft.	6.4 lb./b.h.p.	4.28 lb./sq. ft.	35,280 lb.
40 ,,	8.53 ,,	5.71 ,,	47,040 lb.
50 ,,	10.65 ,,	7.14 ,,	58,800 lb.
60 ,,	12.79 ,,	8.56 ,,	70,560 lb.

The effect of this overloading has been studied in relation to each aspect of performance, from take-off to top speed and back to landing. Its effect was also looked into with regard to performance with one engine and two engines dead, and also with regard to tare weight and disposable load.

3. Performance Analysis.

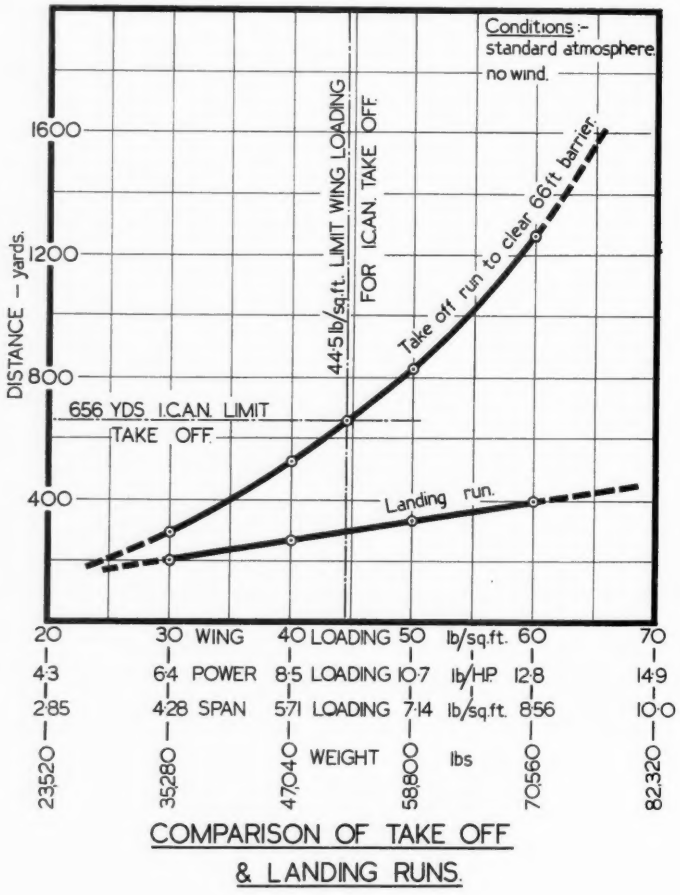
(a) Take-off.

The most pronounced effect of overloading is shown in the length of the take-off run, as might be expected.

In order to find the optimum weight which would allow the aircraft to comply with the I.C.A.N. requirements, every possible benefit was given to the machine.

Constant-speed airscrews were assumed and various kinds of flaps were investigated. It was found that any flap having a high drag was very detrimental at high loadings. In fact, under certain conditions the drag exceeded the thrust before the take-off speed was reached.

The best results were given by Handley Page slotted flaps set down to 30°, with slotted ailerons set down to a neutral position of 20°. In this condition C_L was 0.5 and the C_D was 0.05, both corrected for ground effect with a main plane incidence of 0°. The C_L at the unstick was 1.73 (with slipstream) and the C_L max. (also with slipstream) was 2.5.


Conditions:-
standard atmosphere.
no wind.
DISTANCE — yards.
1600
1200
800
400
44·5 lb/sq.ft. LIMIT WING LOADING FOR I.C.A.N. TAKE OFF
Take off run to clear 66 ft. barrier.
656 YDS. I.C.A.N. LIMIT TAKE OFF.
Landing run.
20 30 WING 40 LOADING 50 lb/sq.ft. 60 70
4·3 6·4 POWER 8·5 LOADING 10·7 lb/H.P. 12·8 14·9
2·85 4·28 SPAN 5·71 LOADING 7·14 lb/sq.ft. 8·56 10·0
23,520 35,280 47,040 WEIGHT 58,800 lbs 70,560 82,320

COMPARISON OF TAKE OFF & LANDING RUNS.

FIG. 10.

A coefficient of friction of 0.03 was assumed again to benefit the machine with unassisted take-off.

The take-off runs to clear a 66 ft. barrier are given in Fig. 10, from which it will be seen that the maximum loading which would satisfy the I.C.A.N. requirements was 44.5 lb. per sq. ft.

(*b*) RATE OF CLIMB AND CEILING.

It is shown in Fig. 11 that the intial rate of climb at sea level drops progressively from 3,180 ft. per min. at 30 lb. per sq. ft. to 1,108 ft. per min. at 60 lb. per sq. ft. These high initial rates of climb are due to the use of 100 octane fuel from the start of the take-off up to 1,500 ft.

The rate of climb at the optimum take-off loading of 45 lb. per sq. ft. was approximately 1,840 ft. per min. at sea level, and 1,175 ft. per min. at 3,000 ft. This is satisfactory.

The absolute ceiling had a straight line variation in inverse ratio with all-up weight, and came down from 27,700 ft. at 30 lb. per sq. ft. wing loading to 12,500 ft. at 60 lb. per sq. ft. The corresponding service ceilings were 26,500 ft. and 10,800 ft.

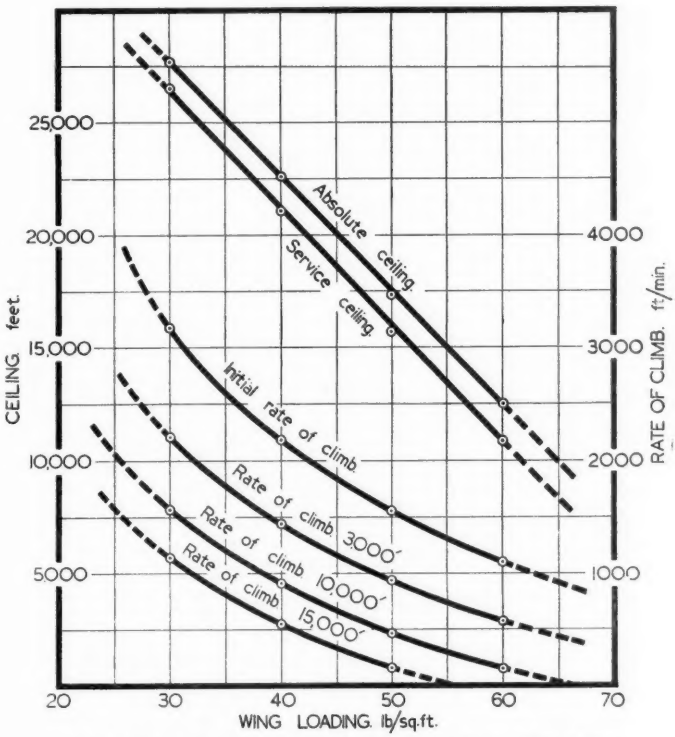


FIG. 11.

A higher aspect ratio might have benefited both rate of climb and ceiling, but the net gain is, of course, not that given by the reduction in induced drag. There would have been an increase in all-up weight for the same useful load, and the beneficial effect of the slipstream would have been less.

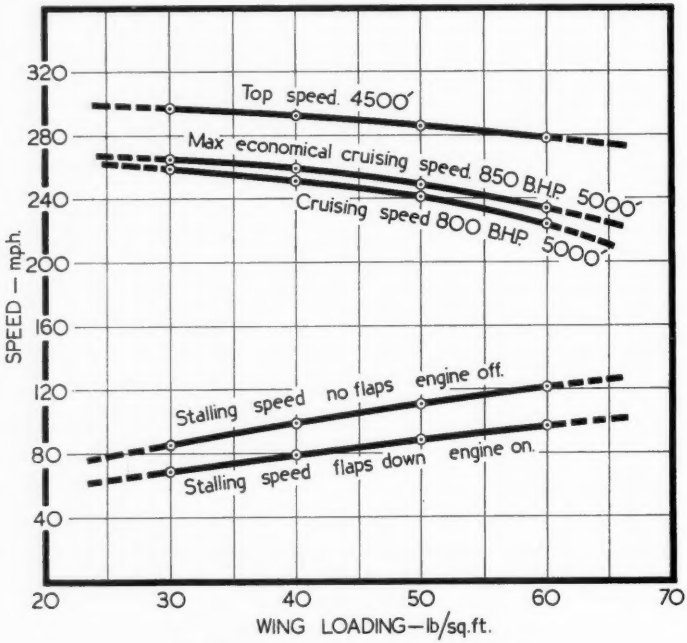
(*c*) TOP AND CRUISING SPEEDS.

There is, of course, an increase in both induced and profile drags as the weight is put up.

The rated altitude of maximum power is 4,500 ft., and at this height the top speed is 297 m.p.h. for 30 lb. per sq. ft. wing loading. Doubling the weight to 60 lb. per sq. ft. reduced the speed to 278 m.p.h., a drop of 6.4 per cent.

Similarly, the maximum continuous cruising speed at 5,000 ft. drops 11.7 per cent. from 265 m.p.h. to 234 m.p.h. as the load is doubled.

At what the engine manufacturers describe as " maximum cruising power for economical specific consumption " (5,000 ft.) the aircraft at 60 lb. per sq. ft. still has a reasonable performance, and there appears to be no reason why the loading should not be made even higher.



COMPARISONS OF SPEED.

FIG. 12.

The ranges and corresponding pay loads are calculated on the speeds corresponding to 800 b.h.p. per engine at 5,000 ft. These drop from 259 m.p.h. at 30 lb. per sq. ft. to 224 m.p.h. at 60 lb. per sq. ft.

The top and cruising speeds are given in Fig. 12.

(d) LANDING.

Stalling speeds are shown in Fig. 12. The calculations show that above 30 lb. per sq. ft. wing loading, the landing run does not go up as fast as the take-off run, with increase of load. In fact, it varies directly with weight, whereas take-off run varies faster than the square of the weight. At all speeds considered the landing run is less and does not give a critical case (see Fig. 10).

At the " optimum take-off loading " of 45 lb. per sq. ft., the landing run is 300 yards, which is slightly better than the official requirements for civil aircraft. These allow a maximum run at 328 yards at this weight.

In calculating the landing run, it was assumed that the wing was at 0° incidence, the main flaps down 60°, and the ailerons set down to a neutral angle of 20°. The tricycle undercarriage allows maximum braking from the moment of touching down.

The gliding speed is, however, high (of the order of 100 m.p.h.). Although a " power " landing is assumed, thus bathing the greater part of the wing in slipstream, and although Handley Page tip slots and a tricycle undercarriage are fitted, it will probably be thought that a loading of 45 lb. per sq. ft. is as yet too high for landing, and that it would not be wise to go beyond 35 lb. per sq. ft. within the next two or three years.

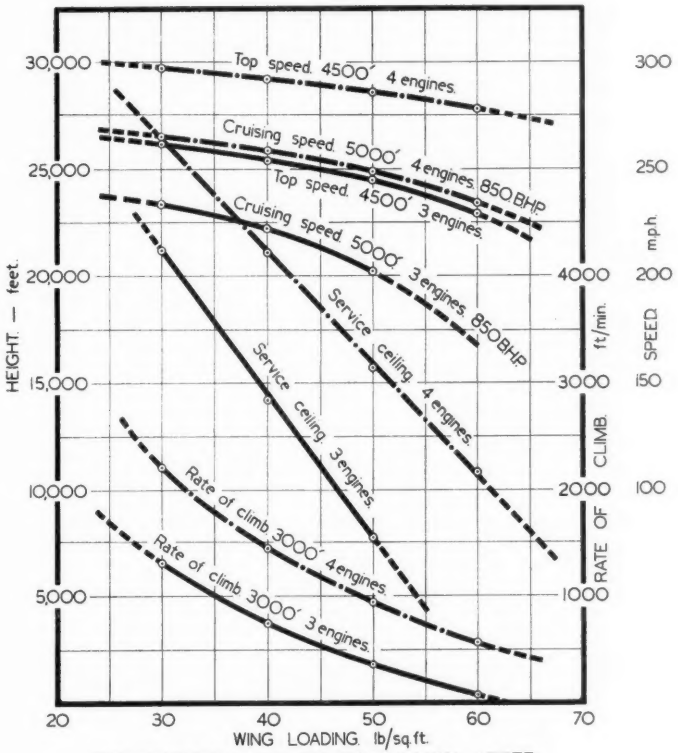


FIG. 13.

With existing aircraft the limiting loading for landing is probably of the order of 30 lb. per sq. ft., and this applies equally well to land aeroplanes and flying boats.

(*c*) PERFORMANCE AFTER ENGINE FAILURE.

The performance has been calculated for the case of one outer engine dead. The following effects are taken into account:—

1. Reduction of available horse-power.
2. Reduction in slipstream effect.

3. Reduction in efficiency of remaining airscrews.
4. Drag of the dead airscrew added, this being assumed feathered to angle of least drag.
5. Increase of drag due to offsetting the rudders and ailerons to compensate for yaw and bank.
6. Increase of induced drag due to distortion of the lift distribution curve along the span.

The method presented to the Royal Aeronautical Society by D. W. Douglas in his Wilbur Wright Lecture (Ref. 8) has been used to establish the effect of these items.

Results of the calculations are given in curves on Fig. 13.

The service ceiling on three engines is reasonably high, varying from 21,000 ft. at 30 lb. per sq. ft. to 7,500 ft. at 50 lb. per sq. ft. wing loading. The rate of climb at 3,000 ft. varies from 1,330 ft. per minute at 30 lb. per sq. ft. to 370 at 50 lb. per sq. ft.

The top and cruising speeds also remain reasonably high, as shown in Fig. 13.

When 60 lb. per sq. ft. loading is reached, flight with one engine dead becomes difficult, although still possible if the throttles of the remaining engines are opened. On the other hand, a jettisoning system will allow the weight to be reduced, and flight continued at some loading about 50 lb. per sq. ft., after which the conditions improve rapidly.

Should one of the outer engines fail during the take-off, the conditions are very different. We have much more power in hand, owing to the use of 100 octane fuel during the take-off. Yet we have a greatly increased drag owing to the fact that the undercarriage and flaps are down.

Further, there may not be time to feather the dead airscrew. Calculations of the rates of climb in this condition show over 1,700 ft. per minute at 30 lb. per sq. ft. wing loading, but a bare 200 ft. per minute at 60 lb. per sq. ft.

Any adverse gust, or even sub-standard atmospheric conditions, would reduce this rate of climb to a negligible quantity and put the heavily-loaded aeroplane into an extremely dangerous position.

One is not encouraged to think of taking-off at wing loadings greater than 30-40 lb. per sq. ft., whether normal or assisted by catapults, inclined runways, and so forth. The safe method appears to be to keep the loading within bounds until a reasonable height is reached, and then to refuel.

Calculations of this sort are not satisfactory in estimating the performance when two engines (on one side) are dead, owing to the much lower speed and the correspondingly high value of the induced drag. Test data of existing aircraft are lacking, and there is little evidence on which to base a " statistical " calculation. However, it may be deduced that the service ceiling would be very low even at 40 lb. per sq. ft., and that above that loading flight would not be possible on two engines (on one side).

Sub-division of the total power into smaller units would improve the position. The point is discussed later.

4. Stability.

The criteria of both longitudinal and lateral stability are not such as to be affected by refuelling in flight, provided that the following precautions are taken:—

1. The air speed at which the refuelling is carried out must not be too low. If the machine is never flown at less than the speed of maximum climb when the overload is on board, all questions of stability in gliding flight are removed. There is no reason why this should ever arise.

2. The moments of inertia about both longitudinal and transverse axes must be kept reasonably small. This condition is observed if the added fuel is stowed as near the centre of gravity as possible. Whilst there is a big problem in such stowage on a small aeroplane, it does not arise in such aircraft as we are studying in this lecture. The centre and leading edge portions of the wing provide more than sufficient space for the load.

The remaining criteria of stability, *e.g.*, dC_L/d_a, tail surfaces, dihedral, etc., are functions of the external aerodynamic shape of the aeroplane, and are not affected by anything internal.

We would point out that the problem is by no means so simple if certain other methods of assisting the take-off of heavily loaded machines are used. By such methods the aeroplane must on occasion be overloaded near the ground, and when flying at slow speeds, but never if refuelling is used.

5. Effects on Tare Weight, Useful Load, Pay Load and Range.

There have been many studies in the past of the increase in size of aircraft and its effect on their tare weights and useful loads, and much controversy aroused on the Cube Law and Square-Cube Law.

In this case, however, the argument is narrowed down to a discussion on the effects of overloading on structure weight. Nevertheless, we are faced with an extrapolation far outside existing practice. At no point in the calculations is it easier to go wrong and to prejudice the result.

In estimating the structure weight we have used a method published by the late Captain F. S. Barnwell in the Journal of the Royal Aeronautical Society in 1937 (Ref. 9) and have checked it by other methods. An error in this estimate would directly affect the amount of pay load carried, and we have, therefore, tried to be conservative.

The structure weight tends to vary at a slower rate than the wing loading, since many items would not be affected by change of loading. Skin thicknesses in normal aircraft, for example, are decided more by the gauge which can be conveniently handled and by conditions of robustness, than by the maximum permissible stress. The ratio of primary to secondary structure varies with the size and purpose of the machine, but in no case does the primary (the weight of which would vary directly with wing loading) approach 100 per cent. of the total structure weight.

This being so, and since the weights of the undercarriage and of the engine installation (excepting fuel system) are not affected by overloads of fuel added in flight, the tare weight must thereby become a smaller percentage of the all-up weight.

This conclusion only holds when the increase in weight occurs at constant dimensions and power. It would certainly not be true if the wing loading were kept constant and the dimensions rose with the weight.

It is thought that the suggested distribution of the engine weight and of the fuel load along so much of the span (see Fig. 21) would tend to give a relatively lower structure weight, but this has not been allowed for in the estimates.

A prominent official in one of the leading air transport companies has expressed the opinion that the limiting loading for landing should be about 30 lb. per sq. ft., but that this view may be modified by further developments in wing sections, flaps, and undercarriages. On the subject of ceiling, he thought that an aircraft having engines supercharged to 5,000 ft. should still be able to operate on its cruising power, with full load on board, at 15,000 ft. Admittedly, these are expressions of opinion, but whilst some may disagree with the actual figures quoted, they do represent an order of things which is desirable in actual air transport operations.

An investigation has accordingly been made into this problem to find if it is indeed a serious criticism of the assisted take-off, whether by catapults, composite aircraft, or refuelling. The answer is that for long range aircraft, designed to carry a reasonable pay load one must either assist the take-off and the initial rate of climb, or else go outside the existing I.C.A.N. regulations governing take-off distance. One must also accept the dangers arising from a very flat angle of climb (perhaps less than 5°). In the transition stage around the actual unstick, the aircraft has to accelerate from its stalling speed up to its best climbing speed with full load on board, this load including all the fuel. The difficulty of maintaining adequate stability and the dangers arising from a possible engine failure during this transition period make the manœuvre an extremely hazardous one, to which passengers and mails should not be lightly subjected.

Most pilots, and most operating companies, too, with the interest of safety at heart, would prefer to take-off light with a short run, to climb away from the ground at a much better angle, and then to refuel at a reasonable height and

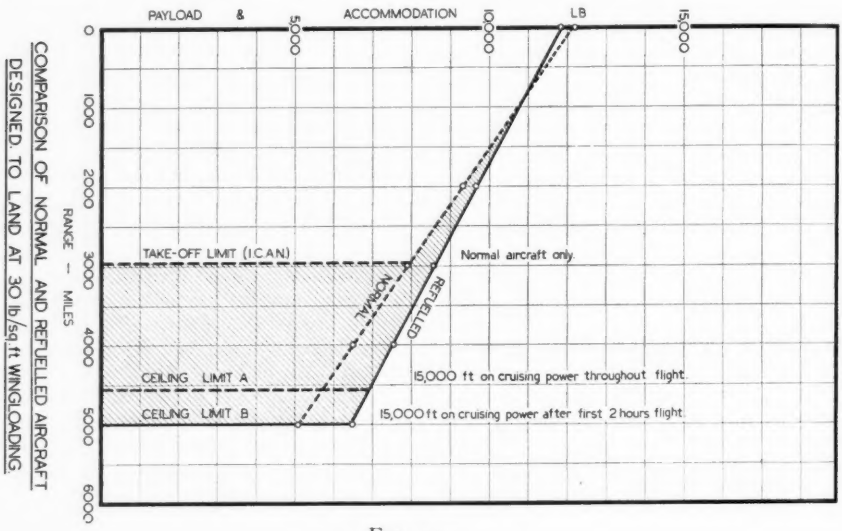


FIG. 14.

speed, when the aircraft is on its course. The refuelling operation means very little to the pilot of the receiving machine. He cannot feel it on his controls, and he is usually only aware of it through the signals he receives from the operators. On several occasions the receiving aircraft has been under the control of the automatic pilot whilst being refuelled.

ASSUMPTIONS.

The hypothetical aircraft chosen as an example for the present investigation is shown in Fig. 9 and its performance and pay load have been compared for ranges of 2,000, 3,000, 4,000, and 5,000 miles. For each range two alternatives were considered, one with a normal take-off and the other taking-off with only 200 gallons of fuel on board, the remainder being added in flight. In order to eliminate from the comparison between the two any unnecessary variables, they have been assumed to have the same wing loading at landing (30 lb. per sq. ft.), the same consumable load, cruising speed, ceiling, etc. In fact, from the moment the refuelled machine has received its load in flight, the two are identical in outward form and performance.

The differences between the two lie in the following points only :—

1. The undercarriage weights are assumed to be 6 per cent. of the take-off weight in each case.
2. The refuelled machine has 250 lb. added for the appropriate equipment.
3. The take-off weight of the normal machine is its full flying weight, whilst the take-off weight of the refuelled one is the same less the weight of all but 200 gallons of fuel.
4. The take-off distances, and the initial climbs are appropriate to the respective take-off weights.

Had a different aeroplane been chosen for the example, the quantitative result might have been rather different, but only to a limited extent, since the hypothetical machine is of the same general type as most modern air transports and heavy bombers (*e.g.*, Short 14/38, Fairey 15/38, Boeing 307 Stratoliner, Boeing XB-15 Bomber, etc.).

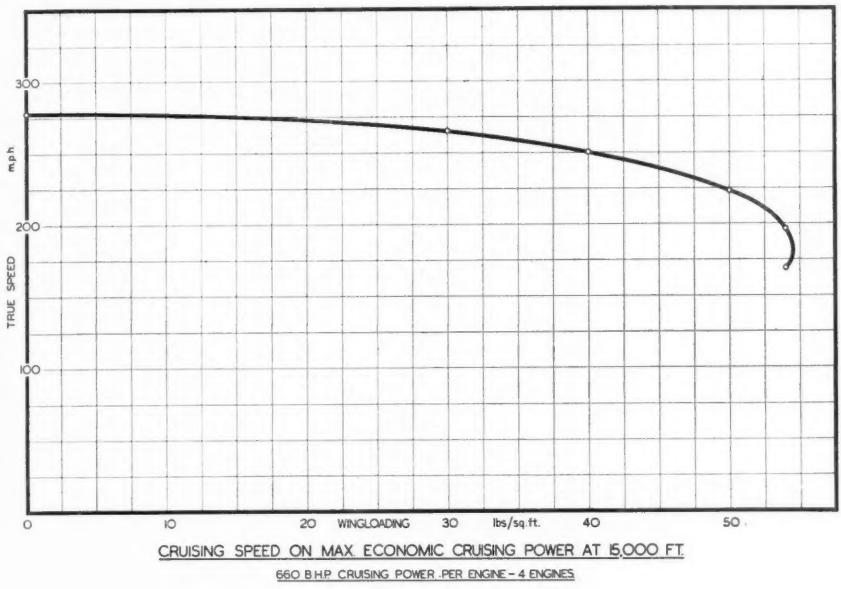


FIG. 15.

CALCULATIONS.

The calculations are given in detail on page 585. Separate estimates have been made for ranges of 2,000, 3,000, 4,000 and 5,000 miles, the aircraft in each case being assumed designed for the range considered. The normal and refuelled aircraft for each range are compared graphically in Figs. 14, 16, 17, 18, and 19.

RESULTS OF INVESTIGATION.

(*a*) LIMIT OF TAKE-OFF.

The final summary of the investigation is given in Fig. 14, in which the weight of " Pay Load plus Accommodation " is plotted against Range for both the normal and refuelled aircraft.

In this particular comparison, all other possible variables being eliminated, the differences in pay load are due only to the different weights of the undercarriage (an appreciable amount), and the weight of the refuelling gear.

At 2,000 miles range the refuelled machine has a pay load 3½ per cent. better, but this grows to 27½ per cent. at 5,000 miles range.*

The normal aeroplane, however, reaches the limit of an I.C.A.N. take-off (656 yards to clear a 66 ft. barrier) at a range of about 3,000 miles. Its initial angle of climb is then 7° 17′, whilst the refuelled machine, taking-off light, has cleared the barrier in 340 yards and is climbing at an angle of 11°.

The normal aeroplane can only work above that range if one of two alternative sacrifices is made. It must either cut its pay load, pound for pound with the additional fuel required, or it must break away from the I.C.A.N. requirements

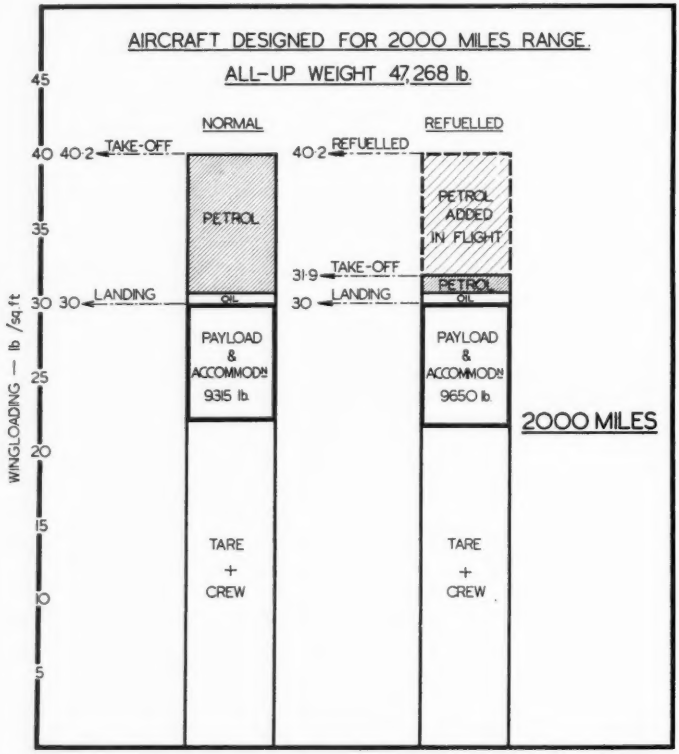


FIG. 16.

	Normal	Refuelled
Cruising speed, average at 5,000 ft. on 800 b.h.p. per engine ...	256 m.p.h.	
Initial rate of climb	2,150 ft. per min.	2,920 ft. per min.
Initial angle of climb	1 in 6.48	1 in 4.69
	8° 48′	12°
Take-off run, to clear 66 ft. barrier	525 yards	330 yards

* The difference in an actual aeroplane might well be greater than this, since the 6 per cent. of the take-off weight assumed for undercarriage is possibly conservative, particularly for a tricycle undercarriage.

for take-off. If the second alternative were chosen, then for 4,000 miles range it would need 860 yards to take-off whilst the refuelled machine was still only taking 350 yards.

At 5,000 miles the position is much worse and the take-off distances are 1,080 yards and 360 yards respectively. The corresponding initial angles of climb are 5° and 11½°.

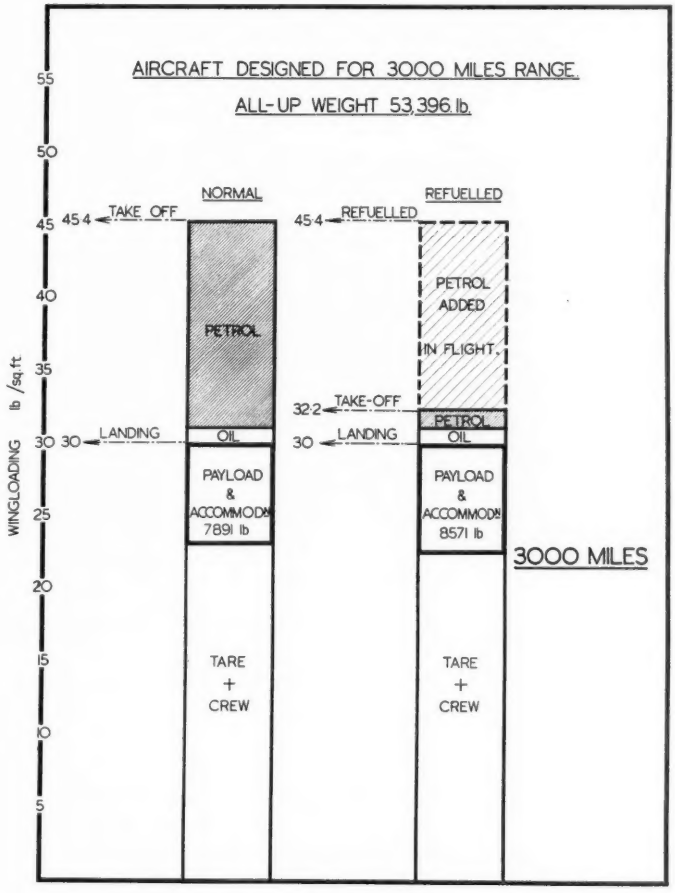


FIG. 17.

	Normal	Refuelled
Cruising speed, average at 5,000 ft. on 800 b.h.p. per engine ...	254 m.p.h.	
Initial rate of climb	1,800 ft. per min.	2,880 ft. per min.
Initial angle of climb	1 in 7.94	1 in 4.76
	7° 12′	11° 50′
Take-off run, to clear 66 ft. barrier	680 yards	340 yards

(*b*) LIMIT OF CEILING.

The large fuel load needed for these long ranges, however, begins to impose the limit of ceiling, and as suggested above the aircraft should be able to operate on normal cruising power at 15,000 ft. so as to clear icing and other bad weather conditions near the ground.

The limit is imposed equally on both normal and refuelled aircraft since they are identical in form and loading, once they have full tanks.

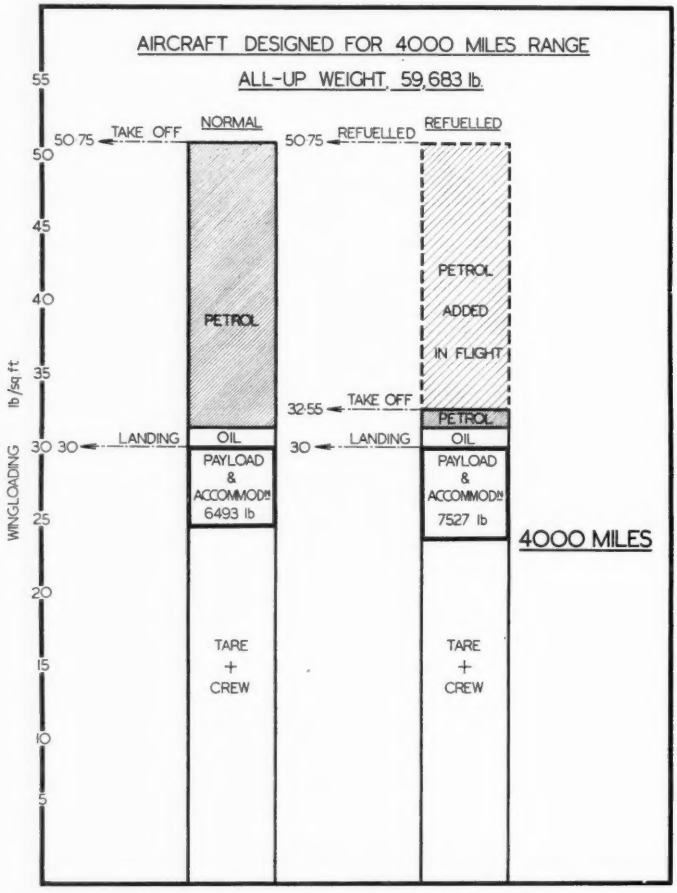


FIG. 18.

	Normal	Refuelled
Cruising speed, average at 5,000 ft. on 800 b.h.p. per engine ...	251.5 m.p.h.	
Initial rate of climb	1,520 ft. per min.	2,840 ft. per min.
Initial angle of climb	1 in 9.44	1 in 4.84
	6° 3′	11° 42′
Take-off run, to clear 66 ft. barrier	860 yards	350 yards

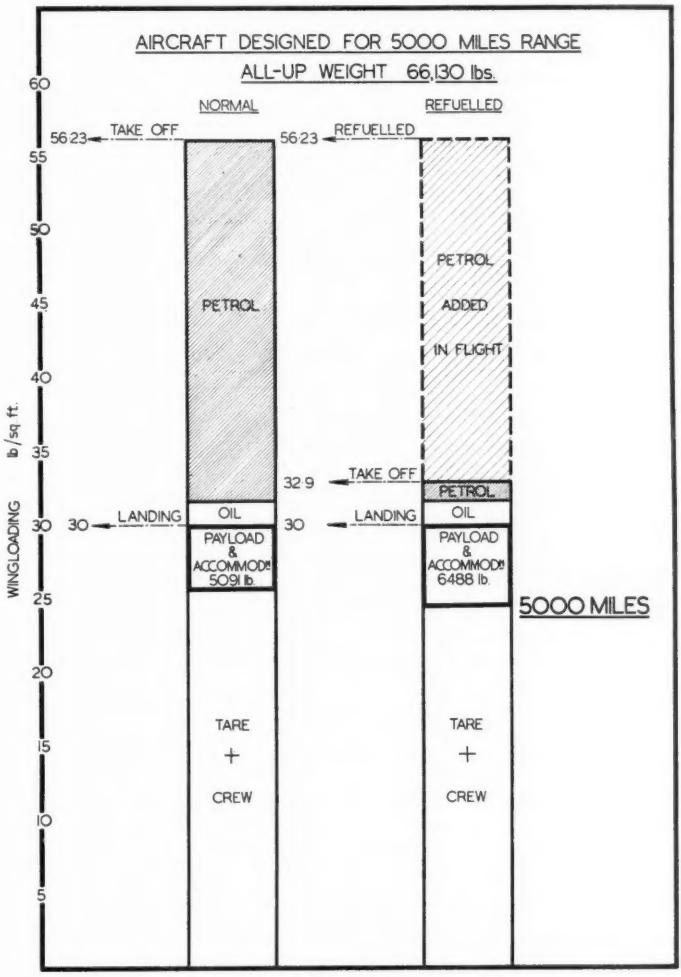


FIG. 19.

	Normal	Refuelled
Cruising speed, average at 5,000 ft. on 800 b.h.p. per engine ...	249 m.p.h.	
Initial rate of climb	1,250 ft. per min.	2,800 ft. per min.
Initial angle of climb	1 in 11.47	1 in 4.91
	5°	11° 30′
Take-off run, to clear 66 ft. barrier	1,080 yards	360 yards

As the load is increased the angle of incidence for a given power must also increase and with it the induced drag. The cruising speed, therefore, drops off slowly at first until at some high loading it dives steeply to zero. For this example we have calculated the cruising speed at 15,000 ft., which would be

available on an engine output of 660 b.h.p. per engine. This is the power at maximum economic cruising revs. for the Hercules IVc engine, which is normally supercharged to give maximum economic cruising power at 5,000 ft. It will be seen from Fig. 15 that the cruising speed drops off from 265 m.p.h. at 30 lb. per sq. ft. wing loading to 223 m.p.h. at 50 lb. Thereafter it falls steeply and it would appear that the Service Ceiling on this power is reached at slightly over 54 lb. per sq. ft. The ceiling condition, therefore, becomes operative at a point between 4,000 and 5,000 miles range if it is to be imposed over the whole flight of the aircraft. This ceiling condition corresponds to the fully loaded aircraft and will actually improve as the flight progresses, due to the burning up of the consumable load. If, therefore, it were felt that a slightly lower standard might be allowed in the first two hours of flight, we may put the ceiling limit at 5,000 miles range.

Basic Data and Assumptions.

The aircraft considered is the Hypothetical Air Liner of Fig. 9.
Cruising on 800 b.h.p. per engine at 5,000 ft.

(4) Future Applications and Developments.

Commercial Air Transport.

We have already given an indication of the kind of air liner which might be used to take advantage of refuelling in flight. It will probably be a medium-sized aircraft, as it would appear that rapid and frequent services would be more desirable than less frequent ones using the giant air liners which have so often been imagined.

With a still air range of 5,000 miles, it would be possible for such aircraft to encircle the world, with stops at Cairo, Bombay, Singapore, Darwin, Sydney, Suva, Honolulu, Vancouver and Quebec. A branch line from Cairo would run to the Cape, with one stop at Mombasa, and South America would be served from England, with one stop at Bathurst. A tropical circuit from Mombasa would connect East and West with Australia, India and South America.

In this way it would be possible to handle all the main routes of the world with some fifteen refuelling stations. The routes would be divided up into convenient stages of 2,500 miles each. No over-sized aerodromes would be necessary, since the aircraft would always take off relatively light, and with machines of this sort it should always be possible to keep well within the I.C.A.N. unstick. In the interests of safety this is important, and doubly so in tropical climates, where adverse conditions may increase the take-off run of a normal aeroplane by as much as 50 per cent. The initial rate of climb would similarly benefit, and the dangers to a heavily-laden aeroplane climbing through the thin and bumpy air of a hot aerodrome completely removed.

Military Applications.

The possibilities of refuelling in military aviation are obvious, but cannot be gone into at the present time. We would, however, re-stress the point already made that grave dangers would arise from a policy which was dependent upon the use of large aerodromes. If these were static, they might be extremely difficult to maintain against enemy action. If they had to be improvised overseas they might be such as completely to prevent the use of heavily loaded bombers.

A Consideration of the Future of Flying Boats.

The effects of weight increment as illustrated in the "land" plane design are, of course, basic, and apply in principle to the flying boat. Since, however, the main force of the argument is direct to "take-off," and since the main reason for the difference between "land" planes and flying boats lies in the different take-off elements of the two, the principle may be expected to apply in rather a different way.

FIRST APPROXIMATION.

Assume: Average cruising speed = 250 m.p.h.
Fuel consumption 192 gallons per hour
Oil consumption 10½ gallons per hour

Range in still air, miles.	2,000	3,000	4,000	5,000
Endurance, hours	8	12	16	20
Total fuel, gallons	1,536	2,304	3,072	3,840
,, ,, lb.	11,520	17,280	23,040	28,800
,, oil, gallons	84	126	168	210
,, ,, lb.	756	1,134	1,512	1,890
,, consumable load, lb. ...	12,276	18,434	24,552	30,690
,, ,, loading, lb./sq. ft.	10.44	15.69	20.9	26.1
Landing loading, lb./sq. ft. ...	30	30	30	30
,, weight, lb.	35,280	35,280	35,280	35,280
All-up loading, lb./sq. ft.	40.44	45.69	50.9	56.1
,, weight, lb.	47,556	53,694	59,832	65,970
Take-off loading, refuelled, lb./sq. ft. (representing 200 gallons fuel + oil at start of flight)	31.9	32.25	32.55	32.9
Take-off weight, refuelled, lb. ...	37,536	37,914	38,292	38,670
Average weight of flight, lb. ...	41,418	44,487	47,556	50,625
,, loading of flight, lb./sq. ft.	35.25	37.8	40.4	43.05
,, speed of flight, m.p.h. ...	256	254	251.5	249

SECOND APPROXIMATION TO CRUISING SPEED.

Range in still air, miles.	2,000	3,000	4,000	5,000
Assumed average speed of flight, m.p.h.	256	254	251.5	249
Endurance, hours	7.82	11.8	15.9	20.1
Total fuel, gallons	1,500	2,270	3,055	3,860
,, ,, lb.	11,250	17,000	22,900	28,950
,, oil, gallons	82	124	167	211
,, ,, lb.	738	1,116	1,503	1,900
,, consumable load, lb.	11,988	18,116	24,403	30,850
,, ,, loading, lb./sq. ft.	10.2	15.4	20.75	26.23
Landing loading, lb./sq. ft.	30	30	30	30
,, weight, lb.	35,280	35,280	35,280	35,280
All-up loading, lb./sq. ft.	40.2	45.4	50.75	56.23
,, weight, lb.	47,268	53,396	59,683	66,130
Take-off loading, refuelled, lb./sq. ft.	31.9	32.2	32.55	32.9
,, weight, refuelled, lb. ...	37,518	37,896	38,283	38,680
Average weight of flight, lb. ...	41,274	44,338	47,481	50,705
,, loading of flight, lb./sq. ft.	35.1	37.7	40.38	43.1
,, speed of flight, m.p.h. ...	256	254	251.5	249

This approximation is complete since the final cruising speeds found are the same as those assumed.

DETAILED WEIGHTS.

Item.	RANGE. Nil		2,000 miles.		3,000 miles.		4,000 miles.		5,000 miles.	
	Normal.	Refuelled.	Normal	Refuelled.	Normal.	Refuelled.	Normal.	Refuelled.	Normal.	Refuelled
Landing Weight, lb.	35,280	35,280	35,280	35,280	35,280	35,280	35,280	35,280	35,280	35,280
„ Loading, lb./sq. ft.	30	30	30	30	30	30	30	30	30	30
Take off Weight, lb.	35,280	35,280	47,268	37,518	53,396	37,896	59,683	38,283	66,130	38,680
„ „ Loading, lb./sq. ft.	30	30	40.2	31.9	45.4	32.2	50.75	32.55	56.23	32.9
All-up Weight Refuelled, lb.		35,280		47,268		53,396		59,683		66,130
„ „ Loading „ lb./sq. ft. ...		30		40.2		45.4		50.75		56.23
(1) *Structure.*										
Wing	5,200	5,200	6,350	6,350	6,900	6,900	7,430	7,430	7,950	7,950
Fuselage	2,860	2,860	3,490	3,490	3,795	3,795	4,085	4,085	4,380	4,380
Tail Unit	780	780	953	953	1,035	1,035	1,115	1,115	1,190	1,190
Undercarriage	2,117	2,117	2,836	2,251	3,204	2,274	3,580	2,296	3,968	2,321
Total Structure	10,957	10,957	13,629	13,044	14,934	14,004	16,210	14,926	17,488	15,841
(2) *Engine Installation.*										
Items (*a*) to (*d*)	9,629	9,629	9,629	9,629	9,629	9,629	9,629	9,629	9,629	9,629
Fuel System	0	0	150	150	227	227	306	306	386	386
Oil „	0	0	82	82	124	124	167	167	211	211
Total Engine Installation	9,629	9,629	9,861	9,861	9,980	9,980	10,102	10,102	10,226	10,226
(3) *Equipment.*										
Items (*b*) to (*e*)	1,075	1,075	1,075	1,075	1,075	1,075	1,075	1,075	1,075	1,075
Refuelling Gear		250		250		250		250		250
Total Equipment	1,075	1,325	1,075	1,325	1,075	1,325	1,075	1,325	1,075	1,325
(4) *Disposable Load.*										
Crew (7)	1,400	1,400	1,400	1,400	1,400	1,400	1,400	1,400	1,400	1,400
Fuel at Take-off	0	0	11,250	1,500	17,000	1,500	22,900	1,500	28,950	1,500
Oil	0	0	738	738	1,116	1,116	1,503	1,503	1,900	1,900
Pay Load and Accommodation ...	12,219	11,969	9,315	9,650	7,891	8,571	6,493	7,527	5,091	6,488
Total Disposable Load	13,619	13,369	22,703	13,288	27,407	12,587	32,296	11,930	37,341	11,288
Summary.										
1. Structure	10,957	10,957	13,629	13,044	14,934	14,004	16,210	14,926	17,488	15,841
2. Engine Installation	9,629	9,629	9,861	9,861	9,980	9,980	10,102	10,102	10,226	10,226
3. Equipment	1,075	1,325	1,075	1,325	1,075	1,325	1,075	1,325	1,075	1,325
4. Disposable	13,619	13,369	22,703	13,288	27,407	12,587	32,296	11,930	37,341	11,288
TAKE-OFF WEIGHT	35,280	35,280	47,268	37,518	53,396	37,896	59,683	38,283	66,130	38,680
Fuel added in flight		—		9,750		15,500		21,400		27,450
ALL-UP WEIGHT...		35,280		47,268		53,396		59,683		66,130

The take-off and alighting is normally less restricted in a flying boat than in the corresponding " land " plane. Wide estuaries or arms of the sea, such as those of Langstone, Southampton, Plymouth and Felixstowe, allow of long runs and slow initial rates of climb.

Gouge has shown (Ref. 10) that the Empire boats, whose normal all-up weight is 40,500 lb., might be loaded to 51,500 lb. without exceeding the I.C.A.N. requirements of take-off within 60 seconds. The wing loading would then be 34.3 lb./sq. ft.

He goes on to say that the Empire boat does not mark the limit of possibilities in available thrust, and that he foresees boats operating under their own power up to a wing loading of approximately 40 lb./sq. ft. He would not advocate such loadings on small boats, but went on to say that loadings will increase to this value with large boats, and particularly with long-range ones.

It will be seen that this limit of 40 lb./sq. ft. is similar to that which we have put forward for a " land " plane of similar size and weight to the Empire boat. If that may with benefit be loaded up to 60-70 lb./sq. ft. when in the air, there is no reason to suppose that the benefit would be less with an Empire, or any other, flying boat.

As Gouge has said, it would probably be necessary to increase the hull beam to avoid dirtiness on the water, and the consequent damage to the airscrew tips from spray.

The use of refuelling in flight removes any excuse for carrying the fuel in the hull. In this connection Gouge said: " The question of petrol stowage is a matter of opinion, but personally I feel that with the petrol in the wings, the aeroplane has improved flying characteristics, and is better from the point of view of the comfort of the passengers."

If the main weight of petrol is never in the boat whilst this is on the water, there will be an improved transverse metacentric height, with consequent reduction in size of wing-tip floats, or stubs, whichever are used

In the discussion which followed the reading of Mr. Gouge's paper before the Royal Aeronautical Society, Major Penny said that Mr. Gouge had remarked that there was no reason why flying boats should not take off at speeds over 100 m.p.h. As he, himself, saw the position, however, the future flying boat would not take off at all under its own power, but would be designed for landing only. If that were so, there would be gained the advantage of smaller hull, less structure weight, and, aerodynamically, more efficiency.

There was also an advantage as regards the engine. An aircraft with the assisted take-off, and, therefore, not requiring the maximum power output of the engine, enables the compression ratio of the engine to be increased, and thus fuel consumption to be reduced.

Major Penny went on to say: " The present disadvantages of the compression-ignition engine would be overcome, and it seems likely that this type of engine will now come into its own for long-distance traffic."

A secondary effect in the case of flying boats is the relationship between airscrew diameter, water clearance, and the frontal area of the hull. If the airscrews are not designed for take-off, but only for climb and cruising considerations, a reduction in diameter is possible.

This, in turn, allows reductions in the distance between the engines and between the wing and the water. Since the hull height is decided by water clearance, and not by the pay-load, a reduction is possible, giving a corresponding improvement in performance. Similarly, a reduction in distance between the engines improves the lateral stability and the conditions should one of the outboard engines fail.

Thus the refuelling of a flying boat in flight allows of two possible alternatives:—

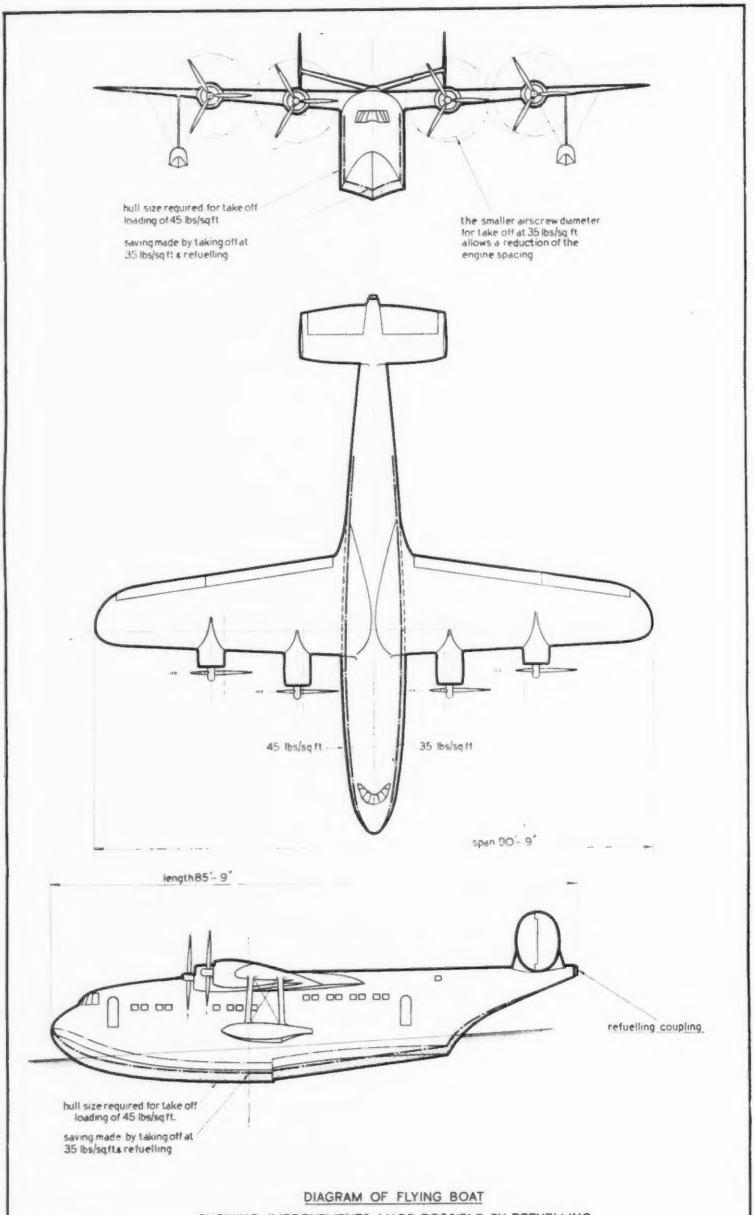

hull size required for take off loading of 45 lbs/sq ft
saving made by taking off at 35 lbs/sq ft & refuelling
the smaller airscrew diameter for take off at 35 lbs/sq ft allows a reduction of the engine spacing
45 lbs/sq ft
35 lbs/sq ft
span 90'- 9"
length 85'- 9"
refuelling coupling
hull size required for take off loading of 45 lbs/sq ft.
saving made by taking off at 35 lbs/sq ft & refuelling
DIAGRAM OF FLYING BOAT
SHOWING IMPROVEMENTS MADE POSSIBLE BY REFUELLING
Flight Refuelling Ltd.
Ford Aerodrome.
Yapton, Sussex.
Drg No. E 1487 27.8.38

FIG. 20.

(1) The addition of extra load to a boat already designed for a heavily-laden take-off, thus increasing the range;
Or

(2) A reduction in take-off load, with consequent reduction in hull beam, hull height and airscrew diameter thus increasing the cruising speed, the load being made up to normal by the addition of the fuel after taking off.

Minor effects would be a reduction in the vertical tail area and in the size of the wing-tip floats.

Fig. 20 shows the improvement which might be made to a flying boat having an all-up wing loading of 45 lb./sq. ft., if it were designed for refuelling after taking off at 35 lb./sq. ft.

It is true that certain of these advantages are given by other methods of assisting the take-off, *e.g.*, catapulting, or the mounting of a boat on a bogie running down an inclined runway. Refuelling, however, is free from the discomfort and low altitude hazard of these. It further provides a mobility which they lack.

Future Development of Engines, Fuels, and Airscrews, in Relation to Refuelling.

The engines used in the "typical" air liner of the calculations are of the Bristol Hercules IV sleeve valve type. Fuel of 100 octane value is used for the take-off and initial climb to 1,500 ft. For the remainder of the climb and for cruising, fuel of 87 octane is used. De Havilland hydromatic airscrews (Hamilton licence) with feathering blades are assumed.

These features mark the limits of take-off thrust at present available commercially, and with them the aeroplane has been shown to have a normal take-off within the limits of the I.C.A.N. regulations up to a wing loading of practically 45 lb./sq. ft. The corresponding power loading is 9.6 lb./h.p.

One asks what are likely to be the effects of future developments in engines, fuels and airscrews on the maximum load which can be taken off the ground, and whether such developments would militate against the present advantages of refuelling in flight.

But before an answer is given to that question, one asks whether it is desirable to go to a take-off loading as high as 45 lb./sq. ft., even supposing the thrust were available. Many transport operators and pilots would be doubtful. They would probably find the hazard of a forced landing immediately after taking off extremely disturbing.

Supposing that one of the four engines cuts out (and in spite of the increasing reliability of engines, this may still happen), the aeroplane would have to land immediately unless the pilot had raised the undercarriage and flaps, and could instantly feather the "dead" airscrew. The stalling speed would be in the region of 100 m.p.h., and the gliding speed perhaps 120 m.p.h. or more.

We will not pretend to answer this question. Having put it, we go back to the previous one of the probable future development of engines, fuels and airscrews. The relationship between engine and fuel is so close that the two must be considered together.

Engine and Fuel Developments.

The power output for a given size and weight of engine has risen steadily, and as far as we can see ahead, it will go on rising. The weight, in pounds per horse-power, has dropped from 1.6 to 1.25 for large engines in the last ten years. The horse-power per litre has risen in the same time from less than 20 to over 40.

Whilst these figures in themselves are of little importance to aircraft designers and transport operators, they are a measure of the improvement in engineering technique. They must be tied up with cowling and cooling drag, and with fuel consumption.

Cowling drag has diminished considerably since the introduction of the Townend and N.A.C.A. types of cowling. The rate of progress under this heading cannot, of course, be maintained, and the one big improvement left is to bury engines completely within the wing.

As engine diameter tends to become smaller in relation to power output and wing thickness, this possibility is within reasonable distance of attainment. Flat, horizontally-opposed engines which would easily go within a wing section could be designed, but the problem of building the structure round them is not small. When that point is reached, cowling drag will, of course, be zero, and we are left only with the drag of the airscrew shaft fairing.

Great progress has been made in cooling drag, and for a high-speed machine a zero or even a negative quantity is within reach.

Regarding fuel consumption, considerable improvement has been made, and much more appears to be possible. The automatic mixture control has contributed much to the regulation of the consumption and the prevention of unnecessary wastage. The improvements in the anti-knock value of fuels have allowed the use of higher compression ratios, with consequent reduction in fuel consumption.

It is generally agreed that a sleeve valve allows the use of one integer of compression ratio higher than a poppet valve operating on the same fuel, with a corresponding reduction in consumption. It does not seem unreasonable to predict that fuel consumptions below 0.42 lb./b.h.p./hour may be obtained if the cruising load is kept below 50 per cent. of the maximum power.

Although the octane " yardstick " breaks down when a value of 100 is reached, a fuel which, by extrapolation, may be named 110 octane, is already being made. It is, of course, costly, but it can be made from available petroleum products, and it is certainly not a chemical curiosity.

This might enable an engine rated on 100 octane fuel and giving a maximum power at, say, 6,000 ft., to be run at full throttle on the ground, *i.e.*, about 20 per cent. above rated power.

For engines fully developed on 100 octane fuel, it is not unreasonable to assume that a specific take-off power of between 35 and 40 h.p./litre will be attained. On that basis the Hercules engines used in the hypothetical air liner of this report might be made to give 1,550 h.p. for take-off.

If that prophecy be a rash one, then it would be even more dangerous to look further. Nevertheless, one wonders where this development can end. Will fuels of even higher octane rating, perhaps alcohol blends, be developed? Will water injection become practical? The responsibility rests as much on the shoulders of the metallurgists as on those of the engine designers. And if such developments take place, may it not be possible to obtain 2,000 h.p. from a weight and size of engine which at present gives 1,380 h.p. for take-off?

Where do these developments lead us? Even supposing it were possible to get an aeroplane off the ground at a wing loading of 50 or 60 lb./sq. ft., is that desirable? Can lift coefficients be so increased, and drag coefficients so reduced, that one could, without hazard, allow such loadings to be used commercially?

Until one can guess as far ahead in aeroplane design as in engine design, it would be dangerous to prophesy. In the meantime, we feel that pilots will impose a limit, and that it would be unreasonable to ask them or passengers to be possible subjects for the disaster which would follow an engine failure in taking off at a wing loading much in excess of 40 lb./sq. ft.

At the same time, if by further subdivision of the total power into smaller units the hazard were reduced and it were possible to take off at higher loadings, then equally it becomes possible to consider higher refuelled loadings of the order, perhaps, of 70 or 80 lb./sq. ft. *With increasing aerodynamic cleanliness the optimum loading becomes higher.*

Subdivision of the total power into more than four separate units increases the power available, should one engine fail. But the chances of such failure are

correspondingly increased. This subject is dealt with more fully on the following pages.

Whilst additional take-off power may possibly be necessary for certain classes of military aircraft (*e.g.*, fighters), we feel that it is likely to be of less use in air liners and heavy bombers, and that the take-off loading will be limited by landing and emergency conditions near the ground. When refuelled in flight, a machine need never be near the ground in an overloaded condition.

Nevertheless, the development of high octane fuels is just as necessary for cruising, particularly when the engines are run at a high percentage of their maximum power. But whatever advantage in fuel economy is added in this way, the same relative advantage is gained by refuelling.

With regard to Diesel engines, there is little one can say, since their development has been very restricted in recent years. Such great strides have been made in the design of spark-ignition engines that the claim of great fuel economy for the Diesel is no longer justified. Nevertheless, with equal money and time spent on it, Diesels might go right ahead again, especially for long-range work.

Their greatest claim is now in the reduction of the fire hazard, and undoubtedly the transport operators would find that a good selling point.

The cheapness of fuel (which may only be temporary and cease when the total amount used makes it tax-worthy) and the simplification of the radio screening are both favourable to the Diesel engine.

It is possible that refuelling would prove a substitute for " ground boosting," and that it would thereby remove one of the limitations on the development of the Diesel. This question has been discussed at some length by Fedden (Ref. 11), and he makes the following point: " Personally, I lean to the view that for long-range night bombers of moderate performance, as well as civil aircraft, there is a great deal to be said for the compression-ignition engine in fairly large sizes and of not less that 1,000 cruising horse-power. It is impossible, however, to take such a high specific output from a given swept volume from the compression-ignition engine, as from the corresponding petrol engine, but it is practicable to take a higher percentage cruising output, from a given size, from the compression-ignition engine, and, if we are to look to mechanically assisted or catapulted aircraft for the future, then the compression-ignition engine has a better chance of coming into its own."

Airscrews.

The question of further subdivision of the total power has been raised on the previous page. This is primarily an airscrew problem.

Four units appears to be the ideal arrangement. The use of two leads to a great hazard, should one engine fail; six or eight units give certain advantages in reduction of wing structure weight, and better distribution of slipstream for the improvement of the maximum lift coefficient.

The first advantage is, however, counteracted by the greater weight of power plant, and the second to some extent by additional drag at high speeds. The high moment of inertia about the longitudinal axis of the machine would raise problems in lateral and directional stability.

Further, the increased risk of engine failure would probably lead to a " two engines dead " or even a " three engines dead " criterion of safety. In that case there would be no gain.

Other arrangements of the airscrews and engines are, of course, possible, as for example:—

(*a*) Tandem engines, one tractor, one pusher.

(*b*) Double concentric airscrews.

This gives the minimum airscrew diameter and weight, but also a much reduced take-off thrust.

(*c*) Two or more engines geared to one airscrew.
This gives the maximum airscrew diameter and weight, and is therefore inadmissible.

It is possible that the problems of tandem engines have been partially solved by the developments in duct cooling and constant-speed airscrews. By their use, one could divide the total power into eight units without any increase in the lateral moment of inertia. This would improve the conditions, should one engine fail in the take-off, and might allow of higher take-off wing loadings. Nevertheless, it is probable that for equal power the take-off lift would be less, owing to reduced slipstream effect.

There are also the problems of having two maximum noise zones in the cabin, and a complication of the ailerons and trailing edge flaps.

Neither in this aspect of the airscrew problem, nor in the future developments in the actual design of the airscrew itself, does one find anything which militates against the advantages of refuelling in flight for high-speed air transports or heavy bombers.

With the nett propulsive efficiency already 85 per cent. (as used in the appended calculations), no great improvement in cruising speed or range is to be expected from the airscrews. There might be a saving in weight of 10 per cent., with the electron blades over the more usual duralumin blades, but this improvement is allowed for in the weight estimates.

Compressed wood blades might show a greater saving, but there would certainly be a loss in efficiency due to the greater blade thickness, and on a long-range machine they would not be worth while.

The limit of useful thrust in the take-off has already been reached for a machine of this type, the deciding factor now being landing speed, and we need not consider any improvement there as a rival to refuelling.

However, another, but perhaps minor, aspect of take-off thrust should be mentioned.

If the maximum possible take-off weight is not required, and if refuelling is substituted for maximum possible take-off thrust, then one can use airscrews of smaller diameter without any great loss of efficiency at cruising speed. This possibility may be of interest where airscrew clearances are a critical factor in the design, as, for example, in certain types of military flying boats, where cruising speed and range are extremely important.

The question of two speed gears has been frequently discussed in relation to take-off thrust, but the problem is too complex for generalisation. Again we can only say that there would be no gain in the design under review, since the condition of high r.p.m. for take-off prevents bad stalling of the blades, and in any case the limiting load is decided by the landing speed.

There have recently been discussions in the technical press on the subject of opposite turning airscrews. This is only related to our problem in as far as it affects the ceiling of an aeroplane after the failure of one or more engines.

There appears to be a marked difference in ceiling, depending on whether a port or a starboard engine is stopped, and it is suggested that a consistent figure for both sides would be given if opposite turning airscrews were used.

Future Developments in Aircraft Structures in Relation to Refuelling.

There is a considerable difference in the effects on the aeroplane structure of different methods of assisting the take-off. Compare, for example, the loads imposed by catapulting with those imposed by refuelling.

In an aeroplane designed for catapulting, there are four spool fittings on the fuselage, two on each side, the front pair of which have to take reactions in any direction, and the rear pair only vertical reactions. Through these fittings are applied loads from the weight of the machine, the torque and thrust of the engine, the thrust of the catapult, and the inertia of the machine.

They are not normally points through which such loads are taken in the degree imposed by the catapult. The great acceleration of the catapult, which may be up to 2.5 g., and which would probably be 1.25 g. even in a commercial aeroplane, imposes inertia loads on every part of the structure, and considerable stiffening is required, particularly in the immediate neighbourhood of the spool fittings.

In refuelling no such sudden and local loads are applied. When the aeroplane is at a safe height, the fuel weight is added at a rate of, perhaps, 1,000 to 1,100 lb. per minute. When refuelled and at its full weight, the aeroplane need never be flown at less than its climbing speed, and no take-off or landing loads of this magnitude are ever applied locally through the undercarriage attachments.

The effect of wing loadings of the order of 50—60 lb. per sq. ft. would be to make the wing structure particularly robust, and the loads would be of such magnitude as to give a very definite stressing case. Consideration of flimsiness and handling loads would no longer apply to those parts affected by the air load. Corrosion per square foot of surface would be the same, but in relation to the bulk of the material, it would be of less importance.

This additional robustness will not only reduce the maintenance charges and the effects of minor damage, but it will equally increase the useful life of aircraft, spreading the obsolescence over a longer period. In this way, the very heavy development costs of large modern aeroplanes can be spread.

Integral Fuel Tanks.

On a large aeroplane the problem of stowing big quantities of fuel does not arise. There is always sufficient space which cannot be used for other purposes.

The main plane, even if not deep enough for cabin space, may still be used for fuel, and the interior of the spar, or the space between conventional dual spars, suggests itself for this purpose.

Apart from the advantage of using this otherwise useless space, it puts the load exactly where it will have least effect on the balance of the aeroplane, and it helps to counteract the large bending moments due to the added weight.

Integral fuel tanks, using the existing main structure, have much to recommend them, particularly in saving weight. In this country they were used in the Supermarine S.5 and S.6 Schneider Trophy seaplanes, where the tanks formed the centre part of the float.

The use of a tubular main plane spar as a tank was suggested and patented by Duncanson (Ref. 12). The development of this idea in England apparently ended with his death, but similar work has been done in Germany by the Hamburger Flugzeugbau G.m.b.H. They have applied it to the design of five different types, ranging from a machine of 19.6 ft. span to one of 88.8 ft. span (Ref. 13).

In America integral fuel tanks have been used by Seversky, Martin, Curtiss Wright, Edo and B/J. A very practical article on this subject by Horace J. Alter (Ref. 14) mentions a number of methods of sealing the seams so that the structure may flex without leaking.

Information as to the additional weight caused by sealing off portions of the structure to act as tanks is, of course, difficult to obtain, but Alter suggests figures which, when translated into terms of imperial gallons, appear roughly as follows :—

Capacity. Imperial gallons.	Additional weight. lb. per gallon.
80—250	1.38—0.22
400—800	0.12—0.07

Assuming a centre box spar in a main plane of similar dimensions to that of the hypothetical air liner of the performance calculations, we have worked out its capacity when used as a tank. The results are surprising in their magnitude (see Fig. 21).

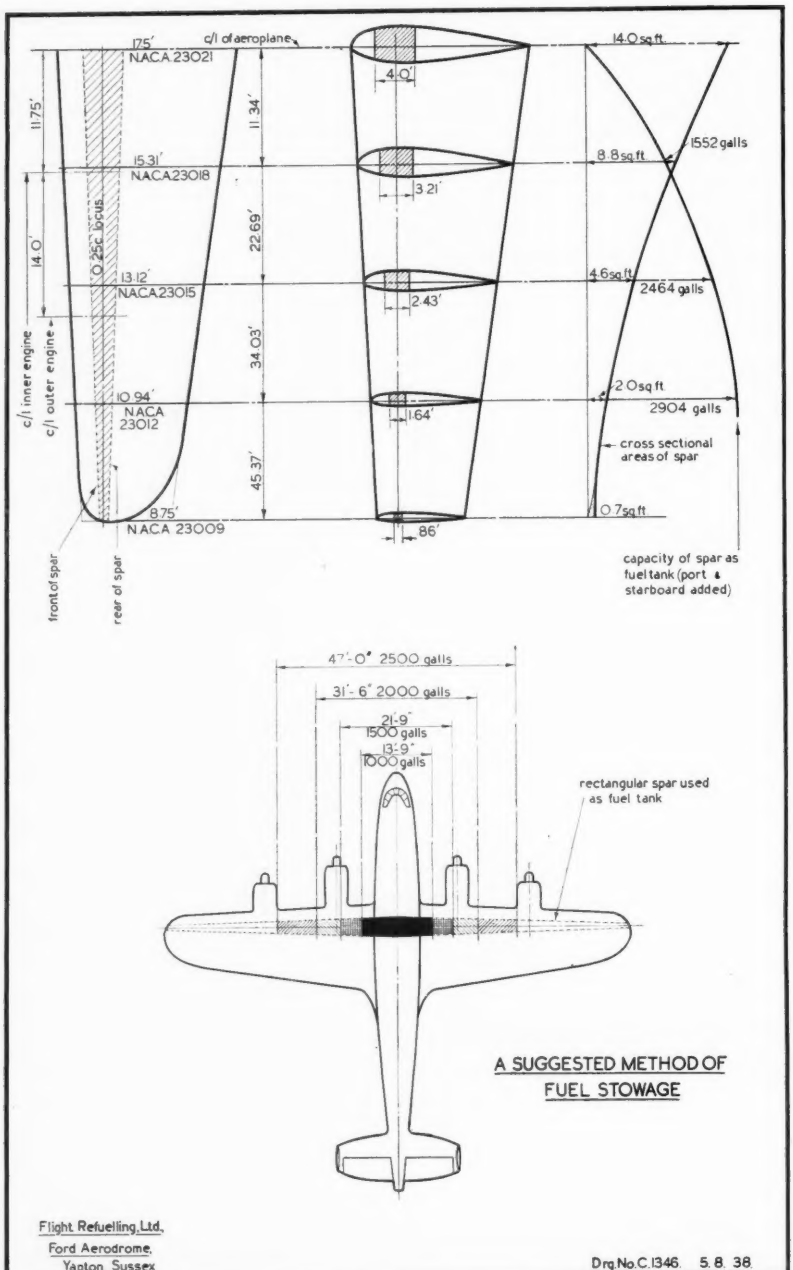

c/l of aeroplane
175'
NACA 23021
11.75'
11.34'
4.0'
14.0 sq ft
1552 galls
15.31'
NACA 23018
8.8 sq ft
3.21'
0.25c locus
14.0'
22.69'
13.12'
NACA 23015
4.6 sq ft
2464 galls
2.43'
c/l inner engine
c/l outer engine
34.03'
10.94'
NACA 23012
2.0 sq ft
2904 galls
1.64'
cross sectional areas of spar
45.37'
8.75'
NACA 23009
0.7 sq ft
.86'
front of spar
rear of spar
capacity of spar as fuel tank (port & starboard added)
47'-0" 2500 galls
31'-6" 2000 galls
21'-9" 1500 galls
13'-9" 1000 galls
rectangular spar used as fuel tank
A SUGGESTED METHOD OF FUEL STOWAGE
Flight Refuelling, Ltd.
Ford Aerodrome.
Yapton, Sussex.
Drg. No. C.1346. 5. 8. 38

FIG. 21.

In a width little greater than that of the fuselage it is possible to stow 1,000 gallons and 2,500 gallons may be put within the span of the outer engines. A wider spar would, of course, give an even greater capacity.

This disposition of the load is ideal, both for structure weight and centre of gravity position. It is possible that the tank weight figures given on page 586 are very conservative if this method is used.

High Altitude Flying.

Much attention has recently been given to high altitude flying, particularly in the United States (Ref. 15). The advantages to be gained may be classified as follows :—

(i) It is dangerous to fly low in the neighbourhood of high mountain ranges, such as the Rockies and Andes, which cross every transcontinental route in both N. and S. America.
(ii) It is possible to fly above all bad weather, cloud, icing conditions, etc., at great heights.
(iii) Higher speeds are possible if the engines are suitably supercharged.
(iv) Use may be made of very high wind velocities occurring at great heights, *if these are favourable.*
(v) For military purposes high altitude flying gives a great advantage to the offensive force and reduces the effectiveness of the defence.

It is difficult to define high altitude flying. No new technique is required, for example, to overcome the difficulties of mountain ranges and bad weather. Normal machines have usually sufficient capacity for height to meet almost any such condition. These do not provide an argument for operation at anything like 30,000 feet.

One cannot generalise on this aspect of the subject. It must be studied in relation to the geography of each particular route. For example, non-stop services between New York and San Francisco would cross the Rockies and Sierra Nevada when near the western end of their run.

In travelling from east to west, sufficient fuel will have been used up to allow them easily to cross the highest points, which are of the order of 14-15,000 feet. On the eastbound run they might take-off with only sufficient fuel to cross the range and be refuelled beyond the top, having still the best part of 2,000 miles to cover.

Induced drag becomes important as both height and wing loading are increased. At first sight there would appear to be a conflict between high altitudes and high wing loading on this account. If, by high altitude is meant anything over 30,000 feet, and if it is realised that such altitudes are only useful when the high velocity wind found there is favourable (an even chance), it becomes obvious that the aeroplane must not be designed so that it can only operate economically at great heights.

It would go to that height only when the wind was favourable, and when such wind would counteract the effect of the higher induced drag.

We can conclude, therefore, that relatively high wing loadings will still be used on high altitude civil machines, and that refuelling holds the same advantage over other methods of assisting their take-off.

For military aircraft, refuelling shows to greatest advantage in long range bombers and reconnaissance machines. Conditions undoubtedly vary in different situations, but in general it may be said that high altitude is not required until some time after the start of the flight. By then sufficient fuel has been used up to permit the machine to climb.

If the maximum military load has been taken off the ground and the fuel added in flight, the effectiveness has thereby been improved. This military load is consequently fixed by the required ceiling when over enemy territory, and not by the necessary fuel to get it there.

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Discussion.

Flight Lieut. G. A. V. Tyson (*Associate*) (Chief Pilot and Manager of the Irish Refuelling Station): Very often both flying and non-flying personnel had expressed the opinion that the flying of a tanker machine was very hazardous; but in fact it was not. Most devices which were not in universal use were regarded with a certain amount of reserve. In that connection he recalled that when he and certain other pilots had first become acquainted with blind approach flying they had not been too optimistic about it, but after a few days of practice they had all come to regard it as a very simple and straightforward matter. So it was with refuelling in the air. Many people thought the operation was bound to be difficult merely because the tanker and the receiving aircraft were connected together by means of a hose; but in fact it was nothing more than a straightforward job of accurate formation flying, and even so a certain amount of elasticity was allowed. The fact that a hose connected the two machines was not even noticeable by the pilot of either of them, and a pilot of average ability could be trained to conquer a tanker machine within a week or a fortnight. Refuelling in flight had been carried out in all weather conditions, and even at night. It could safely be said that the refuelling operation was no more exacting than any other particular type of flying, and no more difficult than getting some aircraft up and down from the ground without damaging them.

Dr. H. Roxbee Cox (*Fellow*): So far, in practice, refuelling had meant changing aircraft of normal capabilities into long-range aircraft, so that it had enabled them to do what otherwise they would not have been able to do for a few more years. From that point of view, of course, the operation of refuelling had been of the greatest value. But one realised that later on, for a given non-stop flight, there would be an aeroplane available which could do without refuelling. That point of view seemed to lead to the prevalent idea that refuelling was an interim measure. But he felt that this outlook was wrong, and it seemed to him that they should try to place the refuelling problem in its proper perspective from the point of view of design. Mr. Langley had made it quite clear that refuelling had very great effects on design, and it was important for designers to know

as soon as possible whether or not they must in the future design with refuelling in view. That was an extremely important matter, but one upon which it was very difficult to come to a decision. In fact, the problem was one of economics and it should be studied carefully. Sir Alan Cobham and Mr. Langley must have thought about it in detail, and he would like to hear their views; roughly, it was a question of whether it was cheaper, for a given non-stop service, to use a number of " self-supporting " aircraft or to use smaller aircraft of higher wing loading, serviced by refuelling. Perhaps the costs of operating air lines had not yet been studied sufficiently to enable them to tackle that question, but they should now begin to give it very serious attention.

The problem of jettisoning fuel was almost as important as that of refuelling itself. It was quite clear that, if a machine could be landed safely at a wing loading of 30 lb./sq. ft., and if it had been refuelled to a wing loading of 60 lb./sq. ft., and if by reason of some mishap it became necessary to land, the extra 30 lb./sq. ft. must be jettisoned, and jettisoned quickly. Thus, de-fuelling was a vital problem, and he hoped it would receive as close a study as the authors had given to the main problem of refuelling.

A few years ago he had belonged definitely to the school which had thought that the aeroplane should be quite self-contained, but he confessed that Sir Alan Cobham and Mr. Langley had seriously disturbed his original point of view, not merely by reason of their advocacy of refuelling as set out in the paper, admirable though it had been, but by reason of their achievements over a number of years. Their experiments had been so well conducted and their success had been so marked that they deserved the most sincere congratulations; he hoped the paper did not mark the culmination of their work, but was merely an interim report.

Mr. LANGLEY: He left the problem of jettisoning to be dealt with by Sir Alan Cobham, but remarked that he still remembered, with regret, the hundreds of gallons that they had thrown overboard in the course of their experiments.

Of course, the authors would like to see design for refuelling; and he agreed that the problem of refuelling was an economic one, involving the comparison between the really large aeroplane incorporating so much space that it could carry all the petrol necessary for long journeys, and the smaller machine which could not do that. Did they really need to use a monstrous flying boat, of hundreds of tons all-up weight, which could be operated economically only on long routes such as the crossing of the Atlantic on a weekly service, or was it not better to use smaller machines and to operate the service daily? Was not that difference the same as the difference between road and rail transport, *i.e.*, the running of a long train once a day, or the running of motor coaches, each carrying smaller numbers of passengers than the train, but much more frequently? He leaned towards the view, which was supported by certain figures, that the smaller machine—by which he meant a machine perhaps bigger than any they were using at present, but smaller than the monstrous flying boat he had mentioned—would be the machine of the future for world air routes, operating daily instead of weekly on long journeys such as to New York. After all, one could travel to New York in four days on the " Queen Mary," so why wait a week to get there quickly. The size of aeroplane for use in the future on such routes must be adapted to the characteristics of the trade.

(*Communicated.*) He understood from Dr. Roxbee Cox after the lecture that he had misunderstood his question, and that it was not that he was discussing the giant flying boat, but rather the difference in the dimensions and cost of manufacture and operations between two aircraft designed for the same range and pay load, one of them with a relatively low wing loading taking off the full load under its own power, and the other of perhaps smaller dimensions and higher loading when refuelled.

The comparison between the two is rather difficult to make. Basically the smaller machine of higher loading should cost less to manufacture. Further, it should cost less to operate in as far as its higher cruising speed would reduce its

time in the air and its petrol consumption for the given range. To this, however, must be added the cost of the refuelling operation. If the refuelling station had a great deal of work to do the cost per operation would be very small. In fact, this cost would vary in almost inverse ratio with the number of refuelling operations per week that it had to carry out.

Sir ALAN COBHAM: He agreed that, where refuelling in flight was adopted, there must be also a perfect system of jettisoning; it was all bound up with the problem of high wing loading. Of course, they had to face the fact that on rare occasions it might be necessary to jettison fuel; and he would rather jettison fuel from a safe height after refuelling than try to do so when in a flat climbing angle in the course of a semi-high wing loaded take-off of 30 or 40 lb./sq. ft. There was really no difficulty to-day about jettisoning fuel; the main consideration was that the fuel should be discharged in such a way that the "angle of spurt" was such as to prevent the fuel coming into contact with the surface of the aircraft during discharge; and it was quite easy to ascertain the point of discharge. Machines varied in their characteristics, but it was clear that, if fuel had to be jettisoned, it must be discharged in the clear air stream outside the disturbed atmosphere immediately around the aircraft. If petrol were discharged at a point too near to the surface of the aircraft, all sorts of comic things might happen; the particles of petrol, after discharge, could be made by atmospheric disturbance to creep forward along the top of the fuselage so that they would eventually come in at the front windscreen. Having provided a jettisoning pipe at the point on the aircraft at which the fuel could be discharged clear of the aircraft surface, one could jettison the fuel without undue risk of fire. Again, he did not think there was any difficulty about designing a mechanical apparatus for jettisoning the fuel. He and his colleagues had considered the matter in great detail and, in fact, they had a whole programme for jettisoning; he believed the operation would be practically automatic, so that a pilot would be able to jettison fuel by merely pressing a button. There were several methods by which fuel could be jettisoned successfully; it was true that a little extra work had to be done on the tanks when they were fitted, but no very heavy apparatus or complicated machinery was involved. It was really elementary.

Discussing the problem of size of aerodromes and Mr. Langley's reference to runs such as 1,000 yards unstick, Sir Alan said it was that question of unstick that had set him thinking about refuelling or loading in the air, some ten years ago. It was all very well to say that in Great Britain, where there were concrete runways and a fairly dense atmosphere, machines of given wing loadings would take-off at 400, 600, or 1,000 yards; but he maintained that as distances for unstick increased, so the variable became greater. Assuming the unstick distance for a particular machine was normally 800 yards, it might quite easily be increased to 1,200 yards as the result of a difference in the condition of the atmosphere as between one day and another. Again, if the machine had to take off from an aerodrome having a surface of long wet grass, instead of concrete, the unstick distance might be increased by 200 or 300 yards. But when they got away from the atmosphere of northern Europe and travelled only as far as the southern coast of the Mediterranean, anything might happen. In the case of the machine having a normal unstick distance of 800 yards in northern Europe, it was conceivable that when at Cairo it might run for 1,600 yards before leaving the ground. That was his experience. At Kisumu, in Central Africa, the aerodrome was at a height of 4,000 ft. above sea level, and the density of the atmosphere there at mid-day might be equivalent to the density at 10,000 ft. in this country. The aeroplane having an unstick distance of 800 yards, when using a concrete runway in this country, might have great difficulty in leaving the ground at all at Kisumu; and even if it did get off the ground it might come down again almost immediately. It seemed that the only solution was some sort of assisted take-off.

Again, a climbing angle of 6° meant sterilising a large area around an aerodrome, and it would be difficult to do that in a compact country such as Great Britain. The aerodrome would need to be at least 1½ miles square or to have a diameter of 1½ or 2 miles, and it would be necessary to sterilise the ground for a distance of 3 or 4 miles all round it; by that he meant that it could be used only for agriculture, and there must be no hills, buildings, or chimneys on it, because the aeroplanes leaving the aerodrome would have to travel several miles before reaching a height of about 1,000 ft. Although a heavily loaded aeroplane might be moving forward at a great rate, its climbing angle would be small, and if the pilot pulled back the stick to clear a hill or a chimney the machine would not rise more steeply. Taking off a machine with a wing loading of 45 or 40 lb./sq. ft., even with all the aids available to-day, was quite hazardous. Even when taking off a machine loaded to 30 or 35 lb./sq. ft. from one of our largest aerodromes, there came a time, just before the unstick, when the pilot had about three seconds in which to decide whether or not he was going to clear the boundary. The machine would be tearing across the aerodrome at great speed, eating up the available running distance of 1,200 or 1,500 yards, and the pilot would be wondering whether he would get off in time. After the three seconds had elapsed he must go on and hope that he would clear the hedge.

Therefore, the only real competitor to refuelling in flight was the large concrete aerodrome, and even then it was necessary to sterilise the ground for a considerable distance around it. In many countries of the world, however, the physical and economic conditions were such that it would be impossible to find sufficiently large aerodrome sites.

Lord SEMPILL (*Fellow*): He congratulated the authors on the very useful work that they had done, and upon the manner of its detailed presentation to the Society, and said that it was particularly appropriate that Lieut.-Colonel Moore-Brabazon, a Past-President, and the first to make a free and controlled power-driven flight in the United Kingdom, should be presiding, and it was particularly appropriate that Colonel Moore-Brabazon should appear before the Society at this moment as it gave them the opportunity of congratulating him on his new appointment as Parliamentary Secretary to the Secretary of State for Air.

Although the authors had referred to catapult launches, an essential method in so far as the Fleet Air Arm was concerned, they made little reference to other methods of launching which might come under the heading of "assisted launches," and it would be useful if they could deal with such methods more fully. The value of refuelling in flight and any other methods that would lead to more useful loads being carried in flight was of an importance that could not be exaggerated to aviation, whether viewed from the military or civil standpoint.

When considering the question of long flights, as for example those of a trans-Atlantic character, the advantages obtained by using the compression ignition engine were considerable. If, for example, a 5 per cent. saving in fuel was made on a trans-Atlantic flight, this would mean a saving in weight of fuel of little short of a thousand pounds.

Mr. LANGLEY: Various methods of mechanical launching other than catapulting were referred to in the paper in more detail than in his verbal presentation of it to the meeting. Reference was made, for instance, to accelerators, engine-driven bogies, inclined runways, etc., and they were all included within the general classification of methods of assisting the take-off by shortening the unstick, but which did not in any way influence the initial rate of climb. One could not argue about the use of catapults on cruisers, for no other method of getting an aircraft off a cruiser could be envisaged. But in respect of relatively large machines, carrying passengers, and so on, and having an all-up weight of perhaps 70,000 lbs., the use of catapults could be regarded as quite out of the question, in the light of experience. Squadron Leader Atcherley had referred to

that matter in his published papers. If an accelerator for launching such an aircraft were mounted on a ship it would cost £100,000; it would be bulky, and in no way mobile or flexible. If it were desired to use such apparatus for military aircraft it might be necessary to instal half a dozen in a row in order to get a squadron of machines in the air quickly, and they would have to be in fixed places from which they could not be moved. Such apparatus was open to criticism for those reasons and for economic reasons, and from the point of view of safety.

He hoped that increased attention would be given to the development of the Diesel engine in the near future, for anything that could be done to further that development would increase the safety of flying.

Mr. P. G. MASEFIELD (*Associate Fellow*): The authors had shown in very convincing ways the advantages of refuelling aircraft during flight; it was not just a stunt, but a very practical everyday job, and it was hoped that even during the War the powers-that-be would see fit to allow its development to continue, in the interests of civil flying. Although the authors had said very little about the refuelling of military aircraft in flight—possibly because of the attentions of the Censor—obviously, there were advantages to be derived from it. And in the military field the problem was not merely one of economics, but one of contributing to the winning of the War. The person who thinks quickest is likely to win the War. In this country Sir Alan Cobham and his associates seemed to have thought more quickly than anybody else on the subject. Although so many practical facts had been put forward, apparently they were being ignored completely by the Air Ministry; but there was more hope so far as the Fleet Air Arm was concerned, as Lord Sempill had suggested. Apparently the policy was to build bigger and bigger bombers, with greater and greater wing loadings, longer and longer runs and flatter and flatter climbs. Somebody had referred to the long take-off as the " assistance-by-prayer " method! But no amount of prayer for assistance would help a pilot very much if an engine cut out or lost power when his machine was staggering off the ground with a load of 10,000 lb. of petrol and 10,000 lb. of bombs. Furthermore, the dropping of a bomb on a long runway might put a whole squadron out of action completely. Again, in considering the use of very big bombers, was it wise to put all one's eggs in one basket?

The solution seemed to be the refuelling in flight method, although other forms of assistance came into the picture. By adopting the refuelling method one could use obsolescent machines to help off the next generation of bombers. There was one rather fundamental question, would bombable objectives be so close that the amount of fuel to be carried was not such as to warrant refuelling in the air? Perhaps the answer to that was that by flying very fast on very high powers the machines could use quite a lot of petrol. However, many people, the pilots not least among them, were disturbed seriously with regard to the long take-off run of the new bombers. One would not question the far-sightedness of the Air Ministry but for its record of suspicion towards new things such as monoplanes, retractable undercarriages, variable-pitch airscrews, and so on, about which it had needed quite a lot of convincing. But they did lead the world in regard to refuelling in the air at the moment; there was evidence that others were thinking about it, and it would be a tragedy if they sprung it on us. Perhaps the paper would encourage those in command to reconsider the facts and possibly to examine the problem of refuelling in another light.

The CHAIRMAN: The paper would be circulated in the Air Ministry.

Mr. A. HESSELL TILTMAN (*Fellow*): As one who had been fortunate enough to be associated with the authors in some of their work on refuelling, he complimented them on the very big contribution they were making to the development of aeronautics. The essential feature of refuelling in the air, he said, was that it increased the range of aircraft, and one could look into the future and feel that increase of range might even make a very important contribution towards

the salvation of international relationships; the ability to cross the world quickly might be very important in years to come.

Discussing some of the advantages of the use of the Diesel engine, Mr. Tiltman emphasised firstly the fact that the flashpoint of Diesel oil was very much higher than that of petrol, so that it was very safe from the point of view of fire. When he read of crashes of civil machines he always registered a certain amount of surprise if the machines concerned had not caught fire. Another advantage of the Diesel engine was that operation costs were reduced by reason of reduced fuel consumption and cost, as compared with petrol, and that reduced fuel consumption enabled the aircraft to carry a greater pay load. Two other advantages of the use of the Diesel engine were that it did not cause interference with radio work by static discharges, and that greater reliability was possible by reason of the elimination of ignition system, carburettor and other accessories which could give trouble.

Commenting that all refuelling operations to date had been effected on converted aircraft, he said there was no case on record in which a machine had been designed for the high wing loadings at present visualised. No machine had the strength to be refuelled to a wing loading of 60 lbs./sq. ft., and until experiments were made in that direction one could hardly expect to reap the full advantage of refuelling in the air. He urged that special consideration be given to the building of a special machine having a wing loading of 70 lb./sq. ft., with a factor of 6, so that research could be carried out up to a loading of 70 or 75 lb./sq. ft.

Quite recently he had made a historical study of refuelling, and some extraordinary results had been achieved with American machines operated for something like 27 days, making 400 contacts, many of them at night and in bad weather, without accident. The only accident in the history of refuelling occurred on the very first occasion on which it was tried in 1923.

He believed Sir Alan Cobham had realised from the very beginning of the work, when the " Courier " was built, that the success of refuelling depended largely on the ability to jettison fuel safely. There were really two ways of jettisoning fuel. It could be carried out within a comparatively few seconds, but the method involved some hazard. In the case of refuelling when the machine was at some considerable altitude, it could be spread over two or three minutes.

Sir Alan Cobham: Refuelling was cheap. At one time it was thought that it would be necessary to design a special tanker for the purpose, but that machines for receiving fuel in the air could be converted from existing aircraft. Now, however, it had come to be realised that it was the receiving aircraft which should be specially designed to take advantage of refuelling; and it seemed that, for many years to come, " last year's models " would make excellent tankers. In the past he had made great plans for a special tanker design, and had calculated how many tankers would be required to cover a world organisation and how much money the tankers would cost. But, for certain reasons, he had great hopes that in the very near future he would be able to pick up a lot of very cheap machines which would make first-class tankers and would last for many a day. On the question of economics it was of interest to note that the tankers would never become worn out, but would die of obsolescence. The engines would serve for long periods without overhaul, because so little of their time was spent in actual flying. Even if a tanker refuelled a service every day, the tanker would be flying for only about an hour per day; if it were refuelling two or three services a day it was still not doing much actual flying. Whilst the cost of refuelling a service once a week might be rather heavy, the cost of refuelling three services a day at a tanker depot would amount to only a few odd pence per gallon surcharged delivered in the air, and that represented a minute fraction of the extra revenue that could be earned by reason of the extra pay load that could be carried in the refuelled machines.

Mr. LANGLEY: With reference to Mr. Tiltman's remarks concerning the design of special aeroplanes for refuelling, he said he would like to see the Diesel engine and the small-hulled flying boat developed with the help of refuelling. The special aeroplanes might with advantage include a small-hulled flying boat fitted with Diesel engines, for it would represent a distinct step forward from anything they knew at present.

Mr. D. L. ELLIS (*Associate Fellow*): His first reaction to the paper was that it provided yet another reason why it was such a crying shame that civil aviation had been allowed to become moribund at the moment. But, whatever might be the ultimate in design, whether aeroplanes were designed for refuelling or simply for range, refuelling did provide them with a system completely developed, and very admirably so, which would enable them to make possible the commercial success of the Atlantic crossing with existing designs.

With regard to performance, he said the initial rate of climb, in the general sense, was the limiting factor of all assisted take-offs; it set a very definite limit to modifications of the wing with slots, and so on. Therefore, the greatest result from refuelling was obtained by refuelling part of the way through the flight. If there were reasons why refuelling stations could not be established part of the way along the route—military reasons, for instance—was there an optimum distance over which a tanker could accompany, say, a bomber? Was it always best to refuel at the place of the initial take-off?

Mr. LANGLEY: He had not considered carefully the point with regard to the tanker accompanying the receiver aircraft for part of its journey in order to refuel it after it had covered that part of its journey. Of course, that scheme would affect the economy, because the tanker would be using fuel while flying. However, the suggestion was worthy of further consideration, and he promised to give Mr. Ellis an answer later.

(*Communicated.*) Further consideration of this problem appears to show that it is dependent on the geography of the particular route under consideration and the characteristics of the aircraft used. As Mr. Ellis has suggested, the military problem is different from the commercial one.

The Irish tankers could not accompany the S.30 flying boats for two or more hours towards America without seriously reducing the amount of fuel that they would eventually deliver. If, however, the tanker used very little fuel per mile, then a delayed contact might be worth while. The problem was again different if the trans-Atlantic liner could take-off from England and be refuelled, without landing, as it passed over the Shannon, outward bound.

A generalised answer would seem to have little value owing to the number of variables.

Flight Lieut. R. C. PRESTON (*Associate Fellow*): Referring to the slides by which Sir Alan Cobham had illustrated the connecting up of the hose pipe from the tanker to the receiver, he said that in one of them the line appeared to come from the receiving aircraft to a point in the side of the tanker, but in the next slide it appeared to be attached to the nose of the tanker. He asked for a further explanation of the manner in which that change was made and incidentally suggested a name should be found for the "receiving aircraft" as simple as that of the "tanker." Apropos of the suggestion, he would propose the term "bunker" in lieu of "receiving aircraft," as being as simple in purpose as "tanker." This would have the additional advantage of enabling them to dispense with the cumbersome word "jettisoning" and at last give them the reasonable interpretation of "debunking," which is long overdue. After all, ships bunker coal, so why not aircraft oil fuel?

He also asked whether the flushing of the hose and pipe lines with nitrogen was effected by the application of pressure.

Finally, he commented on the interest of the paper, and said he would have liked to have seen more representatives of British Overseas Airways present at

the meeting, because it seemed that refuelling in the air must affect long distance flying in the future.

Sir ALAN COBHAM: The nitrogen for flushing the hose and pipe lines was contained in a cylinder under pressure, and when a tap was turned on the nitrogen was forced through the pipes. The pressure was sufficient to flood the nitrogen right down the pipes into the tanks of the receiving aircraft. Just sufficient nitrogen was used to ensure the flooding of the entire system, the quantity having been determined by trial and error; it was measured by means of a gauge glass.

With regard to the connections between the two machines, he said that perhaps Mr. Preston had confused the hose and the line. When the gun fired the projectile and line from the side of the fuselage of the tanker, that line was curled up in a box, the fixed end of it being attached to another line underneath the fuselage and up to the hose. Then the connection was made direct from the nose of the tanker to the tail of the receiving aircraft.

The CHAIRMAN: The hose and hauling line are paid out behind the two aircraft before the final disconnection. How is the disconnection effected?

Sir ALAN COBHAM: There was a weak link in the line; the two aircraft merely flew apart until the line became taut, and the weak link then broke.

The CHAIRMAN: In proposing a hearty vote of thanks to Sir Alan Cobham and Mr. Langley for their paper, commented on Mr. Masefield's remarks concerning the enormous inertia exhibited in some quarters against anything new, and said that that inertia was evident not only in the Air Ministry. In the past there had been enormous difficulty in persuading the motor industry to fit front wheel brakes to vehicles, several years of intensive pushing having been necessary before the powers-that-be would adopt those brakes.

He was delighted, he continued, that the refuelling of aeroplanes in flight had passed beyond the stage at which it was regarded as a stunt and had been recognised as being worthy of a paper delivered to a scientific society, because in fact the process of refuelling was not a stunt. It offered very great advantages, and it seemed to provide a means of overcoming the difficulty of launching. It must not be thought that the machines built for war would be useful for civil aviation, because civil machines of large size, using three-quarters of a ton of fuel an hour, could not be made to pay if they used 100 octane fuel costing 5s. per gallon, unless an enormous contribution was made by the taxpayer; and he saw no reason why the taxpayer should have to pay part of the expenses of people who travelled in aeroplanes. The matter must be considered strictly from the economic point of view, and it seemed that refuelling in the air offered a means of getting back economically to the use of the Diesel engine, which reduced the fire hazard to so great an extent. Whereas the initial take-off boost of the petrol engine, using high octane fuel, had pushed back considerably the possibility of the use of the Diesel engine, the refuelling system seemed to have brought back that possibility, inasmuch as it eased the take-off problem.

He regarded the paper as of great importance, from both the military and the civil points of view, and he would ensure that it was circulated in the right quarters. He proposed the thanks of the Society to the authors for the study they must have given to the subject of refuelling in flight, for the risks they must have taken and for having introduced to the world the possibilities of the system.

(The vote of thanks was carried with acclamation, and the meeting closed.)

THE CALCULATION OF THE LOADS AND BENDING MOMENTS IN RIGID JOINTED FRAMES WITH SPECIAL REGARD TO VARIATION IN SECTION OF MEMBERS.

By J. Morris, B.A.

Summary and Introduction.

The main object of this paper is to put forward a routine method for taking account of the variation in section in the stressing of rigid jointed frames. The formulæ in general use which mainly apply to members of uniform section are suitably modified so as to be applicable to cases where members may be of variable section. The underlying feature of the method is to base the treatment of a rigid jointed frame on the properties of cantilevers loaded at their free ends. Certain deflection coefficients are involved and as shown may be found separately as required for each member. These coefficients may be computed either analytically or graphically. The importance of taking account of variation in section is brought out by practical examples. In certain cases it is shown that very considerable errors may arise if instead of having regard to the actual variable section a mean value is assumed as being sufficiently close from the point of view of the resulting loads. From experience already gained in the application of the method to an actual structure the labour involved is not much in excess of that for the case of the same structure with the sections averaged.

The method does not take end load deflection effects into account and an extension of the method to do this seems desirable. There are, however, many cases in which end load deflection effects are not serious, and in any case it seems useful to have a solution in which these are neglected in the absence of means for obtaining a more comprehensive analysis.

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§1. Deflection Coefficients of a Cantilever of any Section Under Loads Applied at its Free End.

Referring to Fig. 1, let AB be a cantilever encastré at B, and let a load W and a moment M be applied at A, the free end. Let there be an end load P

acting at A in the direction parallel to Bx, the undeflected straight line of the cantilever.

At any point Q on AB distant x from B, the bending moment will be given by

$$M_x = M + W(l-x) + P(\delta_A - y) \quad . \quad . \quad . \quad . \quad (1)$$

so that

$$(EI)_x (d^2y/dx^2) = M + W(l-x) + P(\delta_A - y) \quad . \quad . \quad . \quad (2)$$

where $(EI)_x$ is the flexural rigidity at the point x of the cantilever.

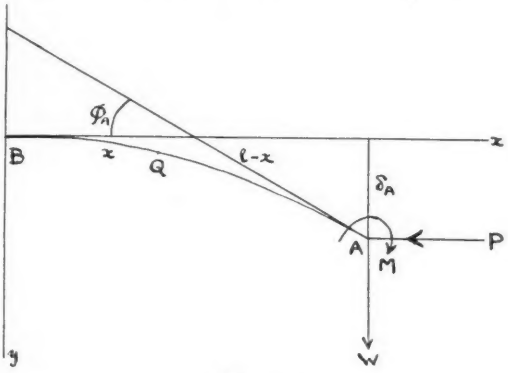


FIG. 1.

Neglecting the end load deflection term in (2) we divide by $(EI)_x$ and integrate between the limits o and l and obtain

$$\phi_A = M\int_0^l \{ 1/(EI)_x \}\, dx + W\int_0^l \{ (l-x)/(EI)_x \}\, dx \quad . \quad . \quad (3)$$

Again multiplying (2) by $(l-x)/(EI)_x$ and integrating between the limits o and l we derive

$$\delta_A = M\int_0^l \{ (l-x)/(EI)_x \}\, dx + W\int_0^l \{ (l-x)^2/(EI)_x \}\, dx \quad . \quad . \quad (4)$$

Let now

$$\phi_{11} = \int_0^l \{ 1/(EI)_x \}\, dx, \quad . \quad . \quad . \quad . \quad . \quad (5)$$

$$z_{11} = \int_0^l \{ (l-x)/(EI)_x \}\, dx, \quad . \quad . \quad . \quad . \quad (6)$$

$$y_{11} = \int_0^l \{ (l-x)^2/(EI)_x \}\, dx; \quad . \quad . \quad . \quad . \quad (7)$$

then (3) and (4) become respectively

$$\phi_A = M\phi_{11} + Wz_{11} \quad . \quad . \quad . \quad . \quad . \quad (8)$$

$$\delta_A = Mz_{11} + Wy_{11} \quad . \quad . \quad . \quad . \quad (9)$$

Clearly y_{11} = deflection at A due to unit load at that point,

z_{11} = slope at A due to unit load at that point, = also deflection at A due to unit couple at that point,

ϕ_{11} = slope at A due to unit couple at that point.

There are two other deflection coefficients which we shall find useful. One is that denoting the direct compression (or extension) due to unit axial or end load. Thus if X is the direct compression (or extension) due to an end load, P,

$$X = Px_{11} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

where

$$x_{11} = \int_0^1 \{ 1/(EA)_x \} \, dx \quad . \quad . \quad . \quad . \quad . \quad (11)$$

where $(EA)_x$ refers to the value of E times the area of cross-section at the point x. The other deflection coefficient applies to the case when the cantilever is subject to a torque, say T, about its axis. In such case if θ is the angle of twist of one end relative to the other then

$$\theta = T\theta_{11}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

where

$$\theta_{11} = \int_0^1 \{ 1/(NJ)_x \} \, dx, \quad . \quad . \quad . \quad . \quad . \quad (13)$$

where N denotes modulus of rigidity and J a function of the cross-section which in the case of a circular member is the polar moment of inertia.

§1.1. Another method of obtaining the foregoing results is by strain energy. Thus the strain energy of the cantilever due to bending will be

$$\tfrac{1}{2} \int_0^1 \{ M_x^2/(EI)_x \} \, dx \quad . \quad . \quad . \quad . \quad . \quad (14)$$

substituting $M + W(l-x)$ for M_x we notice that the integral (14) may be written

$$\tfrac{1}{2} (M^2\phi_{11} + 2\,MWz_{11} + W^2y_{11}) \quad . \quad . \quad . \quad . \quad (15)$$

The strain energy due to direct compression (or extension) will be

$$\tfrac{1}{2} P^2x_{11} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (16)$$

and that due to the torque T (if any)

$$\tfrac{1}{2} T^2\theta_{11} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (17)$$

Thus the total strain energy will be

$$V = \tfrac{1}{2} (M^2\phi_{11} + 2\,MWz_{11} + W^2y_{11}) + \tfrac{1}{2} P^2x_{11} + \tfrac{1}{2} T^2\theta_{11} \quad . \quad . \quad (18)$$

Now

$$\phi_A = \delta V/\delta M = M\phi_{11} + Wz_{11} \quad . \quad . \quad . \quad . \quad (19)$$
$$\delta_A = \delta V/\delta W = Mz_{11} + Wy_{11} \quad . \quad . \quad . \quad . \quad (20)$$
$$X_A = \delta V/\delta P = Px_{11} \quad . \quad . \quad . \quad . \quad . \quad (21)$$
$$\theta_A = \delta V/\delta T = T\theta_{11} \quad . \quad . \quad . \quad . \quad . \quad (22)$$

§1.2. It may be noticed that for a uniform member

$$\phi_{11} = l/EI \quad . \quad . \quad . \quad . \quad . \quad . \quad (23)$$
$$z_{11} = l^2/2\,EI \quad . \quad . \quad . \quad . \quad . \quad (24)$$
$$y_{11} = l^3/3\,EI \quad . \quad . \quad . \quad . \quad . \quad (25)$$
$$x_{11} = l/EA = lk^2/EI \quad . \quad . \quad . \quad . \quad (26)$$

where

$$Ak^2 = I;$$
$$\theta_{11} = l/NJ \quad . \quad . \quad . \quad . \quad . \quad (27)$$

where J is a function of the cross section.

Also

$$\Delta_1 = y_{11}\phi_{11} - z_{11}^2 = l^4/12\,(EI)^2 \quad . \quad . \quad . \quad . \quad (28)$$

§2. Reciprocal Relations between Deflection Coefficients Pertaining to Opposite Ends of a Member.

Regarding the cantilever AB, Fig. 1, as encastré at A and the loads applied at B and denoting the corresponding deflection coefficients by dashes, we have

$$\phi_{11}' = \int_0^l \{ 1/(EI)_{(l-x)} \}\, dx \quad . \quad . \quad . \quad . \quad (29)$$

$$z_{11}' = \int_0^l \{ x/(EI)_{(l-x)} \}\, dx \quad . \quad . \quad . \quad . \quad (30)$$

$$y_{11}' = \int_0^l \{ x^2/(EI)_{(l-x)} \}\, dx \quad . \quad . \quad . \quad . \quad (31)$$

Hence since $x = l-(l-x)$, and $(EI)_{(l-x)} = (EI)_x$,

$$\phi_{11}' = \phi_{11} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (32)$$
$$z_{11}' = l\phi_{11} - z_{11} \quad . \quad . \quad . \quad . \quad . \quad . \quad (33)$$
$$y_{11}' = l^2\phi_{11} - 2\,lz_{11} + y_{11} \quad . \quad . \quad . \quad . \quad (34)$$

and reciprocally, *i.e.*,

$$\phi_{11} = \phi_{11}' \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (35)$$
$$z_{11} = l\phi_{11}' - z_{11}' \quad . \quad . \quad . \quad . \quad . \quad . \quad (36)$$
$$y_{11} = l^2\phi_{11}' - 2\,lz_{11}' + y_{11} \quad . \quad . \quad . \quad . \quad (37)$$

from which we also find that

$$lz_{11} - y_{11} = lz_{11}' - y_{11}' \quad . \quad . \quad . \quad . \quad . \quad (38)$$

and

$$\Delta_1 = \Delta_1' \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (39)$$

where

$$\Delta_1 = y_{11}\phi_{11} - z_{11}^2 \quad . \quad . \quad . \quad . \quad . \quad (40)$$

and

$$\Delta_1' = y_{11}'\phi_{11}' - z_{11}'^2 \quad . \quad . \quad . \quad . \quad . \quad (41)$$

§3. Values of the Deflection Coefficients for a Particular Case.

To gain some idea of the values of the deflection coefficients in the case of a member of variable cross-section we consider a member in the form of a frustrum of a cone as in Fig. 2.

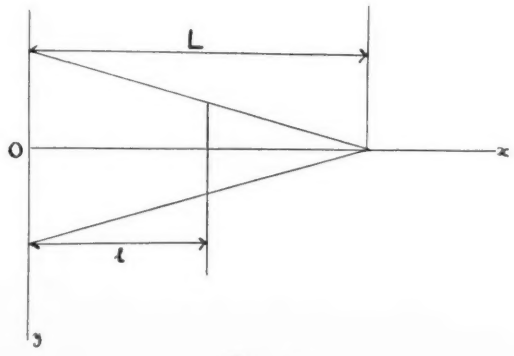


Fig. 2.

We have $I_x = I_o(1-x/L)^4$, where I_x is the flexural moment of inertia at a point along the axis distant x from the base, I_o being the value of I at the base. In these circumstances we obtain

$$\phi_{11} = (1/EI_o)\int_o^l \{\, 1/(1-x/L)^4 \,\}\, dx = (L/3\,EI_o)\,[\,1/(1-l/L)^3 - 1\,] \quad . \qquad (42)$$

$$z_{11} = (1/EI_o)\int_o^l [(l-x)/(1-x/L)^4]dx = (1/EI_o)\int_o^l [(l-L+L-x)/(1-x/L)^4]\, dx,$$

i.e.,

$$z_{11} = (l-L)\,\phi_{11} + (L^2/2\,EI_o)\,[\,1/(1-l/L)^2 - 1\,] \quad . \quad . \qquad (43)$$

$$y_{11} = (1/EI_o)\int_o^l \{\, (l-x)^2/(1-x/L)^4 \,\}\, dx$$

$$= (1/EI_o)\int_o^l [\, \{\, (l-L)^2 + 2\,(l-L)\,(L-x) + (L-x)^2 \,\}\, /(1-x/L)^4]\, dx$$

i.e.,

$$y_{11} = -(l-L)^2\,\phi_{11} + 2\,(l-L)\,z_{11} + (L^3/EI_o)\,[\,1/(1-l/L) - 1\,] \quad . \qquad (44)$$

Let

$$L = 2\,l$$

then

$$\phi_{11} = (14/3)\,(l/EI_o) = 4.667\,(l/EI_o)$$
$$z_{11} = (4/3)\,(l^2/EI_o) = 1.333\,(l^2/EI_o)$$
$$y_{11} = (2/3)\,(l^3/EI_o) = 0.667\,(l^3/EI_o)$$
$$\Delta_1 = y_{11}\phi_{11} - z_{11}^2 = 1.333\,\{\, l^4/(EI_o)^2 \,\}$$

For the mid cross-section of the frustrum

$$I_{L/4} = (81/256)\,I_o$$

in which case we should have for a uniform section of this value for I,

$$\phi_{11} = (256/81)\,(l/EI_o) = 3.160\,(l/EI_o)$$
$$z_{11} = (128/81)\,(l^2/EI_o) = 1.800\,(l^2/EI_o)$$
$$y_{11} = (256/243)\,(l^3/EI_o) = 1.053\,(l^3/EI_o)$$
$$\Delta_1 = y_{11}\phi_{11} - z_{11}^2 = 0.8324\,\{\, l^4/(EI_o)^2 \,\}$$

§4. Artifices in the Calculation of Deflection Coefficients.

In certain cases artifices may be adopted to facilitate the calculation of the deflection coefficients. For example, in the case of the frustrum considered in §3, it is more convenient when using graphical integration to find the values of the coefficients when the cantilever is encastré at the larger end. Those for the condition when the smaller end is encastré then follow from the reciprocal relations (32) to (39).

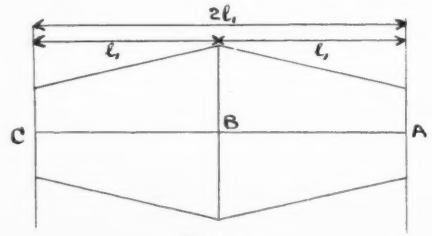


Fig. 3.

§4.1. Let us suppose the member consists of two equal frustrums as in Fig. 3. We have

$$(\phi_{11})_{AC}=\int_0^{2l_1}\{1/(EI)_x\}\,dx=2\int_0^{l_1}\{1/(EI)_x\}\,dx,$$

i.e.,

$$(\phi_{11})_{AC}=2\,(\phi_{11})_{AB} \qquad (45)$$

$$(z_{11})_{AC}=\int_0^{2l_1}\{(2l_1-x)/(EI)_x\}\,dx$$

$$=\int_0^{l_1}\{(2l_1-x)/(EI)_x\}\,dx+\int_{l_1}^{2l_1}\{(2l_1-x)/(EI)_x\}\,dx$$

$$=[2l_1\,(\phi_{11})_{AB}-(z_{11})_{AB}]+(z_{11})_{AB}$$

$$=2\,l_1\,(\phi_{11})_{AB},$$

i.e.,

$$(z_{11})_{AC}=2\,l_1\,(\phi_{11})_{AB} \qquad (46)$$

$$(y_{11})_{AC}=\int_0^{2l_1}\{(2l_1-x)^2/(EI)_x\}\,dx$$

$$=\int_0^{l_1}\{(2l_1-x)^2/(EI)_x\}\,dx+\int_{l_1}^{2l_1}\{(2l_1-x)^2/(EI)_x\}\,dx$$

$$=4\,l_1^2\,(\phi_{11})_{AB}-4\,l_1\,(z_{11})_{AB}+(y_{11})_{AB}+(y_{11})_{AB},$$

i.e.,

$$(y_{11})_{AC}=2\,(y_{11}-2\,l_1z_{11}+2\,l_1^2\phi_{11})_{AB} \qquad (47)$$

We note in this case that

$$(z_{11})_{AC}=l_1\,(\phi_{11})_{AC} \qquad (48)$$

The formulæ thus obtained are evidently quite general for the case where the member is symmetrical about the plane through the cross-section at its mid-point.

§5. Relative Values of Bending and Extensional Strain Energies.

Generally in an unbraced structure the strain energy is mainly due to bending, but in a practical braced structure the extensional energy will usually be predominant. To gain some quantitative idea of the relative values of these energies let us first take the case illustrated in Fig. 4.

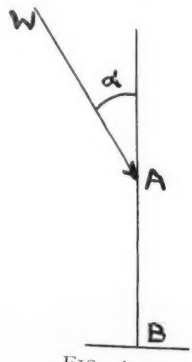


Fig. 4.

AB is a cantilever encastré at B. At A a load W acts at an angle α to BA. This load may be resolved into $W\cos\alpha$ along AB and $W\sin\alpha$ normal to AB.

Neglecting end load deflection effects the strain energy of the member due to direct compression will be

$$V_c=\tfrac{1}{2}\,W^2\cos^2\alpha\,.\,x_{11} \qquad (49)$$

The strain energy due to bending will be

$$V_b=\tfrac{1}{2}\,W^2\sin^2\alpha\,.\,y_{11} \qquad (50)$$

Thus

$$Vb/Vc=(y_{11}/x_{11})\tan^2\alpha \qquad (51)$$

In the case of a uniform member

$$y_{11}=l^3/3\,EI$$
$$x_{11}=lk^2/EI$$

where $Ak^2=I$, the flexural moment of inertia, and A=area of cross section.

Hence

$$Vb/Vc=(1/3)\,(l/k)^2\tan^2\alpha \qquad (52)$$

It is evident, therefore, that when, as is usual l/k is fairly large, say of the order of 100, then Vb will greatly exceed Vc even for relatively small values of α.

For example, let $\tan\alpha=0.05$ for which α is just under 3° and let $l/k=100$. With these values

$$Vb/Vc=25/3 \qquad (53)$$

Let us next take the case illustrated in Fig. 5.

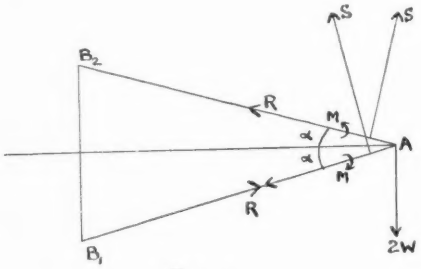


FIG. 5.

AB_1, AB_2, are equal members encastré at B_1, B_2, respectively, and rigidly jointed at A. From consideration of symmetry we assume that the actions of the members on the joint at A will be as shown in the figure. The actions of the joint on the members will, of course, be equal and opposite.

By resolution we find that

$$2\,(R\sin\alpha+S\cos\alpha)=2\,W$$

or

$$R=W\operatorname{cosec}\alpha-S\cot\alpha \qquad (54)$$

There are thus two "redundancies."

The strain energy of AB_1 is

$$V_{AB1}=\tfrac{1}{2}\,(M^2\phi_{11}-2\,SMz_{11}+S^2y_{11})+\tfrac{1}{2}\,R^2x_{11} \qquad (55)$$

and that of AB_2 is

$$V_{AB2}=\tfrac{1}{2}\,(M^2\phi_{11}+2\,SMz_{11}+S^2y_{11})+\tfrac{1}{2}\,R^2x_{11} \qquad (56)$$

Hence the total strain energy of the system is given by

$$V=M^2\phi_{11}+S^2y_{11}+(W\operatorname{cosec}\alpha-S\cot\alpha)^2\,x_{11} \qquad (57)$$

We have, using Castigliano's theorem of least work

$$\partial V/\partial M=0,\ \therefore M=0 \qquad (58)$$

$$\partial V/\partial S=0,\ \therefore S\,(y_{11}+x_{11}\cot^2\alpha)=Wx_{11}\operatorname{cosec}\alpha\cot\alpha \qquad (59)$$

Hence

$$S=(Wx_{11}\operatorname{cosec}\alpha\cot\alpha)/(y_{11}+x_{11}\cot^2\alpha) \quad . \quad . \quad . \quad (60)$$

and consequently

$$R=W\operatorname{cosec}\alpha-S\cot\alpha,$$

or

$$R=(Wy_{11}\operatorname{cosec}\alpha)/(y_{11}+x_{11}\cot^2\alpha) \quad . \quad . \quad . \quad (61)$$

We notice that if

(1) $\alpha=0$, $S=W$, $R=0$.

(2) $\alpha=\pi/2$, $S=0$, $R=W$.

Except when α is in the region of 0, R will, very approximately, have the value W cosec α, which is its value for the case when AB_1, AB_2 are pin-jointed at their ends. Also except in the region when $\alpha=0$, S will usually be small.

We notice that the extensional and bending strain energies are in the ratio

$$S^2y_{11}/R^2x_{11}=(y_{11}/x_{11})\tan^2\alpha \quad . \quad . \quad . \quad . \quad (62)$$

For a uniform member

$$(y_{11}/x_{11})\tan^2\alpha=(1/3)(l/k)^2\tan^2\alpha \quad . \quad . \quad . \quad (63)$$

This is the same as expression (52). Hence we infer that except in the region $\alpha=0$ the extensional strain energy will greatly predominate.

It seems, therefore, that in a braced structure in which loads at the nodes are simple forces and in which the members are of comparable stiffness, that the bending strain energy will be small compared with the extensional strain energy.

The opposite will, however, usually be the case with an unbraced structure.

§6. Application of Method of Deflection Coefficients to the Case of a Simple Portal.

Referring to Fig. 6, let $ABCD$ be a simple portal having a load $2W$ and a couple $2G$ acting at O, the mid-point of BC. Let AB, CD be similar members whose cross-section is not necessarily uniform, and let the member BOC be symmetrical about its mid-point O. Neglecting end load deflection effects and displacements due to extensions or contractions of the members, the portal will be deformed as shown in the figure.

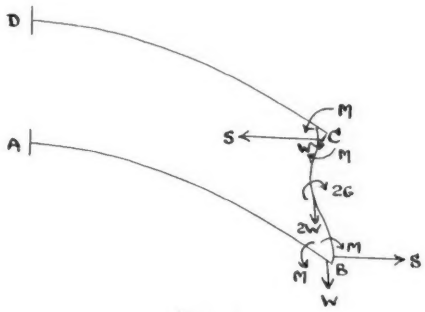


Fig. 6.

So far as the members AB, CD are concerned their ends at B, C, will be subject by the joint to shears W and moments M as shown.

The strain energy of the pair of members will therefore be given by

$$V_1=M^2\phi_{11}-2WMz_{11}+W^2y_{11} \quad . \quad . \quad . \quad . \quad (64)$$

in which the strain energy due to extension or contraction is neglected as being relatively small. The deflection coefficients apply to AB, CD, regarded for the purpose as encastré at A, D, respectively.

So far as the member BC is concerned we have from equilibrium

$$2\,l_2S=2\,(G+M) \quad . \quad . \quad . \quad . \quad . \quad (65)$$

where $l_2=OB=OC$.

The strain energy of these two portions of the member BC will be given by

$$V_2=G^2\phi_{22}-2\,GSz_{22}+S^2y_{22} \quad . \quad . \quad . \quad . \quad (66)$$

where for the purpose of the deflection coefficients OB is regarded as encastré at B. The expression for V_2 is obtained by taking, say, the portion OB for which there will be a shear S and moment G (clockwise) acting at O on the portion OB regarded as encastré at B.

The total strain energy, neglecting that due to extension or contraction, will therefore be given by

$$V=M^2\phi_{11}-2\,WMz_{11}+W^2y_{11}+G^2\phi_{22}-2\,G\,(G+M)\,(z_{22}/l_2)$$
$$+(G+M)^2\,(y_{22}/l_2^2) \quad . \quad . \quad . \quad . \quad . \quad (67)$$

We are left, therefore, with only one "redundancy," viz., M.

Applying Castigliano's principle we have

$$\partial V/\partial M=2\,(M\phi_{11}-Wz_{11})-2\,G\,(z_{22}/l_2)+2\,(G+M)\,(y_{22}/l_2^2)=0 \quad . \quad (68)$$

or

$$M\,(\phi_{11}+y_{22}/l_2^2)=G\,(z_{22}/l_2-y_{22}/l_2^2)+Wz_{11}, \quad . \quad . \quad (69)$$

i.e.,

$$M=[\,G\,(z_{22}/l_2-y_{22}/l_2^2)+Wz_{11}\,]/(\phi_{11}+y_{22}/l_2^2) \quad . \quad . \quad (70)$$

Now

$$Sl_2=G+M,$$

or

$$Sl_2=[\,G\,(\phi_{11}+z_{22}/l_2)+Wz_{11}\,]/(\phi_{11}+y_{22}/l_2^2) \quad . \quad . \quad . \quad (71)$$

To find M_A, we have, with the usual convention,

$$(M_A+M)/l_1=W \quad . \quad . \quad . \quad . \quad . \quad (72)$$

Hence

$$M_A=-M+Wl_1,$$

or

$$M_A=\{\,-G\,(z_{22}/l_2-y_{22}/l_2^2)+Wl_1\,(\phi_{11}-z_{11}/l_1+y_{22}/l_2^2)\,\}\,/(\phi_{11}+y_{22}/l_2^2) \quad (73)$$

§7. Example of Effect of Variable Cross-Section.

Taking the case of §6, with $2\,G$ absent, let the member BOC become infinitely stiff compared with the other two members. In these circumstances y_{22} will be zero. We shall then have

$$M_B=Wl_1\,(z_{11}/l_1\phi_{11}) \quad . \quad . \quad . \quad . \quad . \quad (74)$$

and

$$M_A=Wl_1\,(1-z_{11}/l_1\phi_{11}) \quad . \quad . \quad . \quad . \quad (75)$$

If the members AB, CD are of uniform section then

$$M_B=M_A=\tfrac{1}{2}\,W_1l_1 \quad . \quad . \quad . \quad . \quad . \quad (76)$$

Suppose, however, they are equal frustrums of cones as in Fig. 2, then we have

$$\phi_{11}=(L_1/3\,EI_0)\,[\,1/(1-l_1/L_1)^3-1\,] \quad . \quad . \quad . \quad (77)$$

$$z_{11}=(l_1-L_1)\,\phi_{11}+(L_1^2/2\,EI_0)\,[\,1/(1-l_1/L_1)^2-1\,] \quad . \quad . \quad (78)$$

With these values

$$z_{11}/\phi_{11}=(l_1-L_1)+(3\,L_1/2)\,[\,1/(1-l_1/L_1)-1\,]/[\,1/(1-l_1/L_1)^3-1\,] \quad . \quad (79)$$

We thus obtain the following table:—

l_1/L_1	$z_{11}/l_1\phi_{11}$	$\frac{1}{2}(1-l_1/L_1)$
$\frac{1}{2}$	0.2857	0.25
$\frac{1}{3}$	0.3684	0.3333
$\frac{1}{4}$	0.4054	0.375
$\frac{1}{5}$	0.4262	0.4
$\frac{1}{10}$	0.4649	0.45

We notice, therefore, that the value of the moment at B, *i.e.*, $W_1 l_1 (z_{11}/l_1\phi_{11})$ is considerably affected by the taper as compared with its value for the case when the members are of uniform section.

Column 3 in the table gives a fair approximation to column 2 and may be used for a quick estimate.

If the conically tapered members AB, CD, are hollow and of constant thickness then we have

$$\phi_{11} = \int_0^{l_1} \{ 1/EI_0 (1 - x/L_1)^3 \} \, dx$$

or

$$\phi_{11} = (L_1/2\,EI_0) \, [1/(1 - l_1/L_1)^2 - 1] \quad . \quad . \quad . \quad (80)$$

$$z_{11} = \int_0^{l_1} \{ (l_1 - x)/EI_0 (1 - x/L_1)^3 \} \, dx$$

or

$$z_{11} = (l_1 - L_1) \, \phi_{11} + (L_1^2/EI_0) \, [1/(1 - l_1/L_1) - 1] \quad . \quad . \quad (81)$$

from which we find that

$$z_{11}/l_1\phi_{11} = (1 - l_1/L_1)/(2 - l_1/L_1) \quad . \quad . \quad . \quad . \quad (82)$$

In this case with the member BOC infinitely stiff, as in the previous case, the bending moment at B will be given by

$$Wl_1 \, (1 - l_1/L_1)/(2 - l_1/L_1) \quad . \quad . \quad . \quad . \quad (83)$$

We thereby obtain the following table:—

l_1/L_1				$z_{11}/l_1\phi_{11} = (1 - l_1/L_1)/(2 - l_1/L_1)$
$\frac{1}{2}$	...	...	...	$\frac{1}{3}$
$\frac{1}{3}$	...	...	...	$\frac{2}{5}$
$\frac{1}{4}$	...	...	...	$\frac{3}{7}$
.	...	...	...	.
.	...	...	...	.
.	...	...	...	.
$1/n$	...	...	...	$(n-1)/(2n-1)$

When l_1/L_1 is very small the second column will approximate to $\frac{1}{2}$.

§8. Slope Deflection Formulæ.

Referring to Fig. 7, let AB be the displaced position of a member which before the application of the loads is initially at A_0B_0. If M_{AB}, M_{BA} are the end moments, *i.e.*, the moments *exerted by the joints* A, B, respectively, in the directions shown, then if there is no other loading between A and B,

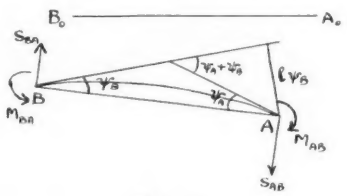


FIG. 7.

the shears at the ends *exerted by the joints on the members* in the directions shown will be

$$S_{BA} = S_{AB} = (M_{BA} - M_{AB})/l \quad . \quad . \quad . \quad . \quad (84)$$

Treating AB as a cantilever encastré at B we have

$$l\psi_B = \{ (M_{BA} - M_{AB})/l \} y_{11} + M_{AB} z_{11} \quad . \quad . \quad . \quad (85)$$

$$\psi_A + \psi_B = \{ (M_{BA} - M_{AB})/l \} z_{11} + M_{AB} \phi_{11} \quad . \quad . \quad (86)$$

Hence we obtain

$$\psi_A = M_{AB} (\phi_{11} - 2 z_{11}/l + y_{11}/l_1^2) + M_{BA} (z_{11}/l_1 - y_{11}/l_1^2) \quad . \quad . \quad (87)$$

$$\psi_B = M_{AB} (z_{11}/l_1 - y_{11}/l_1^2) + M_{BA} (y_{11}/l_1) \quad . \quad . \quad . \quad (88)$$

Now if ϕ_A, ϕ_B are the angular rotations of the joints A, B, respectively, measured in the *same* directions as ψ_A, ψ_B, we notice that

$$\phi_A = \psi_A + \delta_{AB}/l \quad . \quad . \quad . \quad . \quad . \quad . \quad (89)$$

$$\phi_B = \psi_B - \delta_{AB}/l \quad . \quad . \quad . \quad . \quad . \quad . \quad (90)$$

where

$$\delta_{AB} = \delta_A - \delta_B \quad . \quad . \quad . \quad . \quad . \quad . \quad (91)$$

δ_A, δ_B being the vertical displacements of A, B *below* the initial line $A_0 B_0$. If, however, ϕ_B is measured in the same direction as ϕ_A, *i.e.*, *clockwise*, then

$$\phi_B = -\psi_B + \delta_{AB}/l \quad . \quad . \quad . \quad . \quad . \quad . \quad (92)$$

With this convention and substituting for the values ψ_A, ψ_B, in (87) and (88), we find that

$$\phi_A = \delta_{AB}/l + M_{AB} (\phi_{11} - 2 z_{11}/l + y_{11}/l^2) + M_{BA} (z_{11}/l - y_{11}/l^2) \quad . \quad (93)$$

$$\phi_B = \delta_{AB}/l - M_{AB} (z_{11}/l - y_{11}/l^2) - M_{BA} (y_{11}/l^2) \quad . \quad . \quad (94)$$

We notice that if ϕ_B is zero then ϕ_A may be written

$$\phi_A = M_{AB} (\phi_{11} - z_{11}/l) + M_{BA} (z_{11}/l) \quad . \quad . \quad . \quad . \quad (95)$$

Reciprocally (93), (94) may be written

$$M_{AB} = -\delta_{AB} (z_{11}/\Delta_1) + \phi_A (y_{11}/\Delta_1) + \phi_B (l z_{11} - y_{11})/\Delta_1 \quad . \quad . \quad (96)$$

$$-M_{BA} = -\delta_{AB} (l\phi_{11} - z_{11})/\Delta_1 + \phi_A (l z_{11} - y_{11})/\Delta_1 + \phi_B (l^2 \phi_{11} - 2 l z_{11} + y_{11})/\Delta_1 \quad (97)$$

where

$$\Delta_1 = y_{11}\phi_{11} - z_{11}^2.$$

It is sometimes convenient when using the above formulæ to treat M_{BA}, M_{AB}, as acting in the same direction (say clockwise), in which case for $-M_{BA}$ we write M_{BA}.

We notice that if $M_{AB} = 0$, then by eliminating ϕ_A between (96) and (97) we obtain

$$-M_{BA} = (-\delta_{AB}/l + \phi_B) (l^2/y_{11}) \quad . \quad . \quad . \quad . \quad . \quad (98)$$

or if M_{BA} is measured positive clockwise

$$M_{BA} = (-\delta_{AB}/l + \phi_B) (l^2/y_{11}) \quad . \quad . \quad . \quad . \quad . \quad (99)$$

If M_{BA} is zero we find that

$$M_{AB} = (-\delta_{AB}/l + \phi_A) l^2/(l^2\phi_{11} - 2 l z_{11} + y_{11}) \quad . \quad . \quad . \quad (100)$$

which is the same as

$$M_{AB} = (-\delta_{AB}/l + \phi_A) (l^2/y_{11}) \quad . \quad . \quad . \quad . \quad . \quad (101)$$

where y_{11} now refers to the member AB as a cantilever encastré at A. For the shears we have

$$S_{BA} = S_{AB} = (M_{BA} - M_{AB})/l$$

i.e.,

$$S_{BA} = S_{AB} = \delta_{AB} (\phi_{11}/\Delta_1) - \phi_A (z_{11}/\Delta_1) - \phi_B (l\phi_{11} - z_{11})/\Delta_1 \quad . \quad (102)$$

If we use the convention that the shears taken as exerted by the member on the joints are positive in the direction shown in Fig. 7, then we change the sign of the right hand side of (102).

§9. Examples of Application of Slope Deflection Formulæ.

As an example of the application of the use of the " slope deflection " formulæ let us consider the following problem :—

Referring to Fig. 8, AB_1, AB_2, are equal members encastré at B_1, B_2, respectively, and rigidly jointed at A at which point a couple $2G$ acts in the plane

B_1AB_2. This problem can be readily solved by the application of Castigliano's principle as was done in the second example of §5, in which the $2G$ is replaced by a load $2W$ acting vertically downwards. But to illustrate the use of the formulæ in §8 we will employ the " slope deflection " method.

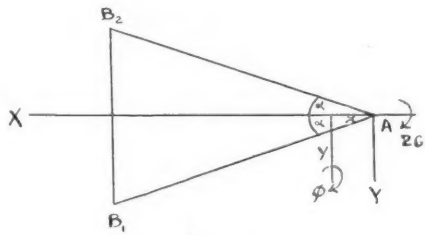


FIG. 8.

Assuming that the point A experiences displacements X, Y, along AX, AY, respectively, and a rotation ϕ clockwise, then compression of AB_1

$$= X\cos\alpha + Y\sin\alpha$$

and elongation of AB_2

$$= -X\cos\alpha + Y\sin\alpha.$$

Also

$$\delta_{AB1} = -X\sin\alpha + Y\cos\alpha \quad . \quad . \quad . \quad . \quad (103)$$

$$\delta_{AB2} = X\sin\alpha + Y\cos\alpha \quad . \quad . \quad . \quad . \quad (104)$$

The shear on the joint due to the bending of AB_1 will be (using (102) and noting that $\phi_B = 0$)

$$-\delta_{AB1}(\phi_{11}/\Delta_1) + \phi(z_{11}/\Delta_1) \quad . \quad . \quad . \quad . \quad (105)$$

Similarly the shear due to AB_2 will be

$$-\delta_{AB2}(\phi_{11}/\Delta_1) + \phi(z_{11}/\Delta_1) \quad . \quad . \quad . \quad . \quad (106)$$

The forces on the joint will therefore be as shown in Fig. 9. These forces, apart from any moments at A, must be in equilibrium. Hence, resolving horizontally,

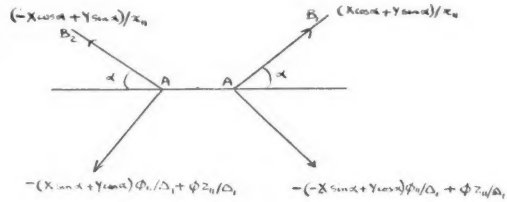


FIG. 9.

$$\{(-X\cos\alpha + Y\sin\alpha)/x_{11}\}\cos\alpha - (X\sin\alpha + Y\cos\alpha)(\phi_{11}/\Delta_1)\sin\alpha + \phi(z_{11}/\Delta_1)\sin\alpha$$
$$= \{(X\cos\alpha + Y\sin\alpha)/x_{11}\}\cos\alpha - (-X\sin\alpha + Y\cos\alpha)(\phi_{11}/\Delta_1)\sin\alpha + \phi(z_{11}/\Delta_1)\sin\alpha$$

$$\text{or } 2X\{(\cos^2\alpha)/x_{11} + (\phi_{11}\sin^2\alpha)/\Delta_1\} = 0 \quad . \quad . \quad (107)$$

so that $X = 0$.

Resolving vertically we obtain the equation

$$Y\{(\sin^2\alpha)/x_{11} + (\phi_{11}/\Delta_1)\cos^2\alpha\} = \phi(z_{11}/\Delta_1)\cos\alpha \quad . \quad (108)$$

The shears at A are, therefore, equal and are given by

$$S = -Y\cos\alpha(\phi_{11}/\Delta_1) + \phi(z_{11}/\Delta_1) \quad . \quad . \quad . \quad (109)$$

So far as the moments are concerned

$$M_{AB1} = -\delta_{AB1}\,(l\phi_{11} - z_{11})/\Delta_1 + \phi\,(lz_{11} - y_{11})/\Delta_1 \quad . \quad . \quad (110)$$

and

$$M_{AB2} = -\delta_{AB2}\,(l\phi_{11} - z_{11})/\Delta_1 + \phi\,(lz_{11} - y_{11})/\Delta_1 \quad . \quad . \quad (111)$$

And since $X = 0$, $\delta_{AB2} = \delta_{AB1}$, hence

$$M_{AB2} = M_{AB1} = G \quad . \quad . \quad . \quad . \quad (112)$$

Treating AB_1 as a cantilever encastré at B_1 with a force $-S$ and a couple acting at A, we have

$$\phi = -Sz_{11} + G\phi_{11} \quad . \quad . \quad . \quad . \quad . \quad (113)$$

or, using the value of S above,

$$\phi = Y \cos\alpha\,(z_{11}\phi_{11}/\Delta_1) - \phi\,(z_{11}^2/\Delta_1) + G\phi_{11}$$

leading to

$$\phi = Y \cos\alpha\,(z_{11}/y_{11}) + G\,(\Delta_1/y_{11}) \quad . \quad . \quad . \quad (114)$$

But we have previously obtained another relation between ϕ and Y, viz.,

$$\phi\,(z_{11}/\Delta_1)\cos\alpha = Y\,\{\,(\sin^2\alpha)/x_{11} + (\phi_{11}/\Delta_1)\cos^2\alpha\,\} \quad . \quad (115)$$

From these two relations we find that

$$Y\,\{\,(\sin^2\alpha)/x_{11} + (\cos^2\alpha)/y_{11}\,\} = G\,(z_{11}/y_{11})\cos\alpha \quad . \quad (116)$$

and

$$\phi\,\{\,(\sin^2\alpha)/x_{11} + (\cos^2\alpha)/y_{11}\,\} = (G/y_{11})\,\{\,(\Delta_1\sin^2\alpha)/x_{11} + \phi_{11}\cos^2\alpha\,\} \quad (117)$$

Using these values we obtain for S.

$$S = (Gz_{11}\sin^2\alpha)/(x_{11}\cos^2\alpha + y_{11}\sin^2\alpha) \quad . \quad . \quad . \quad (118)$$

The forces on the members AB, AB_2, are given by

$$Y\sin\alpha/x_{11} = (Gz_{11}\sin\alpha\cos\alpha)/(x_{11}\cos^2\alpha + y_{11}\sin^2\alpha) \quad . \quad (119)$$

To obtain the moments at B_1, B_2, we have, if these moments are taken as clockwise by the joints on the members,

$$M_{AB1} + M_{BA1} = lS \quad . \quad . \quad . \quad . \quad . \quad (120)$$

from which we obtain

$$M_{B1A} = G\,[(lz_{11} - y_{11})\sin^2\alpha - x_{11}\cos^2\alpha]/(x_{11}\cos^2\alpha + y_{11}\sin^2\alpha) \quad (121)$$

This example, except for end load deflection effects, has been solved by an "exact" method.

§9.1. In the example which follows the foregoing procedure would prove tedious, mainly owing to lack of symmetry. We will, therefore, resort to approximations based on information already derived.

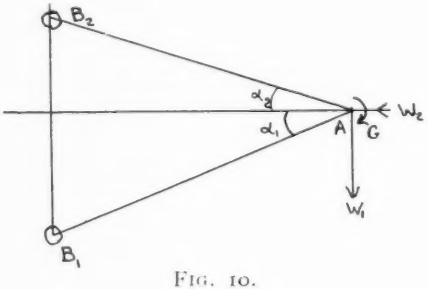


FIG. 10.

Referring to Fig. 10, let AB_1, AB_2, be two unequal members rigidly jointed at A, but pin-jointed at their ends B_1, B_2. At A let forces W_1, W_2, act in the directions shown.

In the first place we will deal with the effect of G alone. In this case the main contribution to the energy will be by bending and the changes in lengths of the members will not very appreciably affect the moments M_{AB1}, M_{AB2}. Hence making use of (99) in which δ is regarded as zero, the moment G will distribute itself in AB_1, AB_2, in the proportions

$$l_1/y_{11} : l_2/y_{22} \quad . \quad . \quad . \quad . \quad . \quad (122)$$

in which the y's are calculated on the basis that AB_1, AB_2, are cantilevers encastré at A.

Thus we shall have moments

$$M_{AB1} = G\,(l_1/y_{11})/(l_1/y_{11} + l_2/y_{22}) \quad . \quad . \quad . \quad (123)$$

and

$$M_{AB2} = G\,(l_2/y_{22})/(l_1/y_{11} + l_2/y_{22}) \quad . \quad . \quad . \quad (124)$$

Since the moments at B_1, B_2, are zero the shears exerted on the joint A by the two members meeting there will be

$$S_1 = M_{AB1}/l_1 \quad . \quad . \quad . \quad . \quad . \quad (125)$$

and

$$S_2 = M_{AB2}/l_2 \quad . \quad . \quad . \quad . \quad . \quad (126)$$

in the directions shown in Fig. 11.

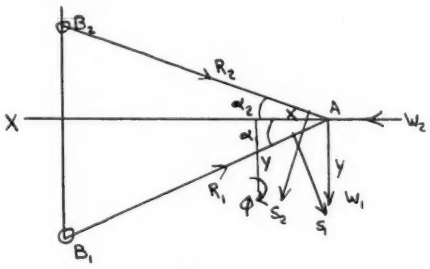


FIG. 11.

We next find the loads in the members AB_1, AB_2, by resolving the forces W_1, W_2, S_1, S_2, in their directions, and let us suppose that these loads are R_1, R_2, both compressive. Then if X, Y are the displacements of A in the directions AX, AY, we have

$$X \cos \alpha_1 + Y \sin \alpha_1 = R_1 x_{11} \quad . \quad . \quad . \quad . \quad (127)$$

and

$$X \cos \alpha_2 - Y \sin \alpha_2 = R_2 x_{22} \quad . \quad . \quad . \quad . \quad (128)$$

From these two equations we can determine X and Y. Next we obtain

$$\delta_{AB1} = -X \sin \alpha_1 + Y \cos \alpha_1 \quad . \quad . \quad . \quad . \quad (129)$$

and

$$\delta_{AB2} = X \sin \alpha_2 + Y \cos \alpha_2 \quad . \quad . \quad . \quad . \quad (130)$$

We then obtain M_{AB1}, M_{AB2}, as follows:—

$$M_{AB1} = (-\delta_{AB1}/l_1 + \phi)\,(l_1^2/y_{11}) \quad . \quad . \quad . \quad . \quad (131)$$

$$M_{AB2} = (-\delta_{AB2}/l_2 + \phi)\,(l_2^2/y_{22}) \quad . \quad . \quad . \quad . \quad (132)$$

in which use is made of (99) and the deflection coefficients are as for cantilevers encastré at A.

Now

$$M_{AB1} + M_{AB2} = G \quad . \quad . \quad . \quad . \quad . \quad (133)$$

hence

$$-\{\delta_{AB1}\,(l_1/y_{11}) + \delta_{AB2}\,(l_2/y_{22})\} + \phi\,(l_1^2/y_{11} + l_2^2/y_{22}) = G \quad . \quad . \quad . \quad . \quad (134)$$

Thus we may determine ϕ.

With δ_{AB1}, δ_{AB2}, and ϕ known, M_{AB1}, M_{AB2}, are readily determined.

We may now obtain the next approximation for the shears S_1, S_2, as follows:—

$$S_1 = M_{AB1}/l_1 \quad . \quad . \quad . \quad . \quad . \quad (135)$$

$$S_2 = M_{AB2}/l_2 \quad . \quad . \quad . \quad . \quad . \quad (136)$$

and thereby obtain the next approximations for R_1, R_2. But this will usually be unnecessary. The values already obtained will generally be sufficiently approximate for practical purposes.

§9.2. If in this same example B_1, B_2, are encastré instead of being pin-jointed, we observe from (96) that having regard to the assumptions previously made, G will be distributed in the ratio

$$y_{11}/\Delta_1 : y_{22}/\Delta_2 \quad . \quad . \quad . \quad . \quad . \quad (137)$$

where y_{11}, Δ_1 : y_{22}, Δ_2, refer to the members AB_1, AB_2, as cantilevers encastré at B_1, B_2. This will not necessarily be the same as the ratio

$$l_1/y_{11} : l_2/y_{22} \quad . \quad . \quad . \quad . \quad . \quad (138)$$

where y_{11}, y_{22}, refer to the same members encastré at A. Thus the distribution will be

$$M_{AB1} = G\,(y_{11}/\Delta_1)/(y_{11}/\Delta_1 + y_{22}/\Delta_2) \quad . \quad . \quad . \quad (139)$$

$$M_{AB2} = G\,(y_{22}/\Delta_2)/(y_{11}/\Delta_1 + y_{22}/\Delta_2) \quad . \quad . \quad . \quad (140)$$

and from (97) we notice that

$$M_{BA1} = \{\,(l_1 z_{11} - y_{11})/y_{11}\,\}\, M_{AB1} \quad . \quad . \quad . \quad (141)$$

$$M_{BA2} = \{\,(l_2 z_{22} - y_{22})/y_{22}\,\}\, M_{AB2} \quad . \quad . \quad . \quad (142)$$

all moments being taken positive clockwise. Hence

$$S_1 = (M_{AB1} + M_{BA1})/l_1 = (z_{11}/y_{11})\, M_{AB1} \quad . \quad . \quad . \quad (143)$$

or

$$S_1 = G\,(z_{11}/\Delta_1)/(y_{11}/\Delta_1 + y_{22}/\Delta_2) \quad . \quad . \quad . \quad (144)$$

Similarly

$$S_2 = G\,(z_{22}/\Delta_2)/(y_{11}/\Delta_1 + y_{22}/\Delta_2) \quad . \quad . \quad . \quad (145)$$

We next find R_1, R_2, as before. Then X, Y, as before, and thus δ_{AB1}, δ_{AB2}. Using (96) we next find

$$M_{AB1} = -\delta_{AB1}\,(z_{11}/\Delta_1) + \phi\,(y_{11}/\Delta_1) \quad . \quad . \quad . \quad (146)$$

and

$$M_{AB2} = -\delta_{AB2}\,(z_{22}/\Delta_2) + \phi\,(y_{22}/\Delta_2) \quad . \quad . \quad . \quad (147)$$

From the fact that

$$M_{AB1} + M_{AB2} = G \quad . \quad . \quad . \quad . \quad . \quad (148)$$

we are enabled to find ϕ, and knowing the δ's and ϕ, we can find the first approximation to M_{AB1} and M_{AB2} for the system of loads.

Also

$$M_{BA1} = -\delta_{AB1}\,\{\,(l_1\phi_{11} - z_{11})/\Delta_1\,\} + \phi\,\{\,(l_1 z_{11} - y_{11})/\Delta_1\,\} \quad . \quad (149)$$

and

$$M_{BA2} = -\delta_{AB2}\,\{\,(l_2\phi_{22} - z_{22})/\Delta_2\,\} + \phi\,\{\,(l_2 z_{22} - y_{22})/\Delta_2\,\} \quad . \quad (150)$$

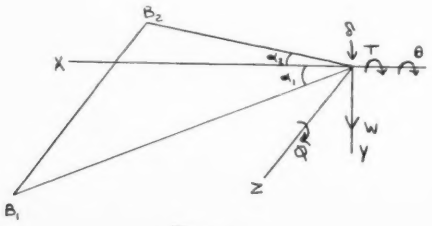


FIG. 12.

We now have a first approximation to all the loads and moments and may, if necessary, proceed to the next approximation by an adjustment of the shears S_1, S_2, and thence R_1, R_2, and so on.

§9.3. To take one more illustration, consider the problem represented in Fig. 12. AB_1, AB_2, are two unequal members rigidly jointed at A and encastré at B_1, B_2, respectively. A torque T acts round the axis AX and a load W normal to the plane B_1AB_2.

Let A receive a displacement δ vertically downwards, a rotation θ about AX in the direction Y to Z and a rotation ϕ about AZ in the direction Y to X. The rotations about various axes through A are as shown in the plan view (see Fig. 13).

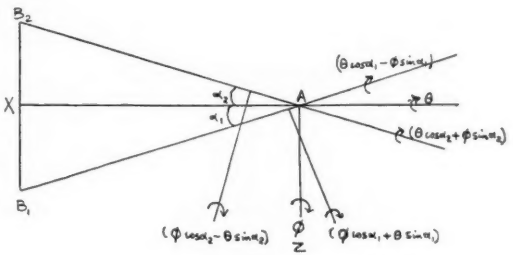


FIG. 13.

Taking moments and torques as positive by the joint on the members we have

$$T_{AB1} = (\theta \cos \alpha_1 - \phi \sin \alpha_1)/\theta_{11} \quad . \quad . \quad . \quad . \quad (151)$$

$$T_{AB2} = (\theta \cos \alpha_2 + \phi \sin \alpha_2)/\theta_{22} \quad . \quad . \quad . \quad . \quad (152)$$

where θ_{11}, θ_{22}, are torsional constants for the members AB_1, AB_2.

$$M_{AB1} = -\delta\,(z_{11}/\Delta_1) + (\phi \cos \alpha_1 + \theta \sin \alpha_1)\,(y_{11}/\Delta_1) \quad . \quad . \quad (153)$$

$$M_{AB2} = -\delta\,(z_{22}/\Delta_2) + (\phi \cos \alpha_2 - \theta \sin \alpha_2)\,(y_{22}/\Delta_2) \quad . \quad . \quad (154)$$

In addition to moments there will be torques in AB_1, AB_2, as follows:—

In AB_1

$$(\theta \cos \alpha_1 - \phi \sin \alpha_1)/\theta_{11}$$

and in AB_2

$$(\theta \cos \alpha_2 + \phi \sin \alpha_2)/\theta_{22}$$

where θ_{11}, θ_{22}, are such that if ψ_1, ψ_2, be the angles of twist in the members AB_1, AB_2, and T_1, T_2, the corresponding torques

$$\psi_1 = T_1\theta_{11} \quad . \quad . \quad . \quad . \quad . \quad (155)$$

$$\psi_2 = T_2\theta_{22} \quad . \quad . \quad . \quad . \quad . \quad (156)$$

Resolving along AX we obtain

$$T = T_{AB1} \cos \alpha_1 + T_{AB2} \cos \alpha_2 + M_{AB1} \sin \alpha_1 - M_{AB2} \sin \alpha_2 \quad . \quad (157)$$

and along AZ

$$-T_{AB1} \sin \alpha_1 + T_{AB2} \sin \alpha_2 + M_{AB1} \cos \alpha_1 + M_{AB2} \cos \alpha_2 = 0 \quad . \quad (158)$$

Also the shear due to the member AB_1 on the joint A will be (see (102))

$$S_1 = -\delta\,(\phi_{11}/\Delta_1) + (\phi \cos \alpha_1 + \theta \sin \alpha_1)\,(z_{11}/\Delta_1) \quad . \quad . \quad (159)$$

and similarly

$$S_2 = -\delta\,(\phi_{22}/\Delta_2) + (\phi \cos \alpha_2 - \theta \sin \alpha_2)\,(z_{22}/\Delta_2) \quad . \quad . \quad (160)$$

For equilibrium we must have

$$S_1 + S_2 + W = 0 \quad . \quad . \quad . \quad . \quad . \quad (161)$$

We now have sufficient equations to determine δ, θ, and ϕ. And having found these quantities the various moments and torques readily follow.

§10. THEOREM OF THREE MOMENTS.

Referring to Fig. 14, let AB, BC, be two consecutive members of a plane frame, rigidly jointed at B, but not necessarily in the same straight line. The members are supposed to be free from any distributed loading.

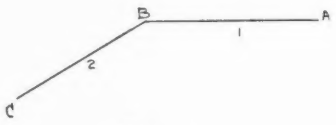


FIG. 14.

Adopting the usual convention that moments which tend to "hog" the members are positive we have

(1) For AB (see (94))

$$\phi_B=\delta_{AB}/l_1-M_{AL}\,(z_{11}/l_1-y_{11}/l_1^2)-M_{BR}\,(y_{11}/l_1^2) \quad . \quad . \quad (162)$$

(2) For BC (see (93))

$$\phi_B=\delta_{BC}/l_2+M_{BL}\,(\phi_{22}-2\,z_{22}/l_2+y_{22}/l_2^2)+M_{CR}\,(z_{22}/l_2-y_{22}/l_2^2) \quad . \quad (163)$$

where M_{AL} denotes the moment just to the left of A, M_{BR} that just to the right of B, and so on.

Equating these two expressions for ϕ_B we obtain

$$M_{AL}\,(z_{11}/l_1-y_{11}/l_1^2)+[M_{BR}\,(y_{11}/l_1^2)+M_{BL}\,(\phi_{22}-2\,z_{22}/l_2+y_{22}/l_2^2)]$$
$$+M_{CR}\,(z_{22}/l_2-y_{22}/l_2^2)=\delta_{AB}/l_1-\delta_{BC}/l_2 \quad . \quad . \quad . \quad (164)$$

in which the δ's refer to differences of displacements of the ends of the members *normal* to their original positions.

It is to be noted that in the expression (164) the deflection coefficients are taken as applying to the members regarded as cantilevers encastré at the left ends; thus, for AB at B and for BC at C.

It may sometimes be more convenient to use deflection coefficients pertaining to ends different from those adopted in (164). For example, if for purposes of the deflection coefficients AB is taken as encastré at B and BC at B, then, having regard to the reciprocal relations between these coefficients, and dropping the dashes (164) will become

$$M_{AL}\,(z_{11}/l_1-y_{11}/l_1^2)+[M_{BR}\,(y_{11}/l_1^2)+M_{BL}\,(y_{22}/l_2^2)]$$
$$+M_{CR}\,(z_{22}/l_2-y_{22}/l_2^2)=\delta_{AB}/l_1-\delta_{BC}/l_2 \quad . \quad . \quad . \quad (165)$$

If for purposes of the deflection coefficients AB is regarded as encastré at A and BC at C, then (164) becomes

$$M_{AL}\,(z_{11}/l_1-y_{11}/l_1^2)+[M_{BR}\,(\phi_{11}-2\,z_{11}/l_1+y_{11}/l_1^2)+M_{BL}\,(\phi_{22}-2\,z_{22}/l_2+y_{22}/l_2^2)]$$
$$+M_{CR}\,(z_{22}/l_2-y_{22}/l_2^2)=\delta_{AB}/l_1-\delta_{BC}/l_2 \quad . \quad . \quad . \quad (166)$$

Finally, if for purposes of deflection coefficients AB is regarded as encastré at A and BC at B (164) becomes

$$M_{AL}\,(z_{11}/l_1-y_{11}/l_1^2)+[M_{BR}\,(\phi_{11}-2\,z_{11}/l_1+y_{11}/l_1^2)+M_{BL}\,y_{22}/l_2^2]$$
$$+M_{CR}\,(z_{22}/l_2-y_{22}/l_2^2)=\delta_{AB}/l_1-\delta_{BC}/l_2 \quad . \quad . \quad . \quad (167)$$

We notice that if the member AB is actually encastré at A then the theorem of three moments for AAB may be written either

$$(1)\quad M_{AL}\,y_{11}/l_1^2+M_{BR}\,(z_{11}/l_1-y_{11}/l_1^2)=-\delta_{AB}/l_1 \quad . \quad . \quad (168)$$

or

$$(2)\quad M_{AL}\,(\phi_{11}-2\,z_{11}/l_1+y_{11}/l_1^2)+M_{BR}\,(z_{11}/l_1-y_{11}/l_1^2)=-\delta_{AB}/l_1. \quad (169)$$

according to whether the member is regarded for purposes of the deflection coefficients to be encastré at A or B.

Alternatively, if the member AB is actually encastré at B, then the theorem may be written

$$M_{AL}(z_{11}/l_1 - y_{11}/l_1^2) + M_{BR}(y_{11}/l_1^2) = \delta_{AB}/l_1 \quad . \quad . \quad (170)$$

or

$$M_{AL}(z_{11}/l_1 - y_{11}/l_1^2) + M_{BR}(\phi_{11} - 2z_{11}/l_1 + y_{11}/l_1^2) = \delta_{AB}/l_1 \quad . \quad (171)$$

according to whether the member is regarded for purposes of the deflection coefficients to be encastré at B or A.

§ 11. Example of Application of Theorem of Three Moments.

As an example of the application of theorem of three moments as obtained in § 10, consider the problem of § 6. For OCD we have, using (164),

$$M_{OL}(z_{22}/l_2 - y_{22}/l_2^2) + [M_{CR}(y_{22}/l_2^2) + M_{CL}(\phi_{11} - 2z_{11}/l_1 + y_{11}/l_1^2)] + M_{DL}(z_{11}/l_1 - y_{11}/l_1^2) = \delta_{OC}/l_2 - \delta_{CD}/l_1 \quad . \quad . \quad . \quad (172)$$

For MDD we have, using (170),

$$M_{CL}(z_{11}/l_1 - y_{11}/l_1^2) + M_{DR}(y_{11}/l_1^2) = \delta_{CD}/l_1 \quad . \quad . \quad (173)$$

From a consideration of the shear in DC

$$M_{DR} - M_{CL} = Wl_1 \quad . \quad . \quad . \quad . \quad . \quad (174)$$

But with the convention implicit in (164) we have

$$M_{OL} = G.$$
$$M_{CL} = M_{CR} = M_C, \text{ say.}$$
$$M_{DL} = M_D.$$

Also

$$\delta_{OC} = O.$$

Let

$$\delta_{CD} = \delta_1.$$

The three equations (172), (173), (174), may therefore be written

$$G(z_{22}/l_2 - y_{22}/l_2^2) + M_C(y_{22}/l_2^2 + \phi_{11} - 2z_{11}/l_1 + y_{11}/l_1^2) + M_D(z_{11}/l_1 - y_{11}/l_1^2) = -\delta_1/l_1 \quad . \quad . \quad . \quad (175)$$

$$M_C(z_{11}/l_1 - y_{11}/l_1^2) + M_D y_{11}/l_1^2 = \delta_1/l_1 \quad . \quad . \quad . \quad (176)$$

and

$$M_D - M_C = Wl_1 \quad . \quad . \quad . \quad . \quad . \quad (177)$$

Adding (175) and (176) and using (177) we obtain

$$G(z_{22}/l_2 - y_{22}/l_2^2) + Wl_1(z_{11}/l_1) + M_C(\phi_{11} + y_{22}/l_2^2) = o \quad . \quad (178)$$

This, having regard to the sign conventions in the two methods, agrees with the result for M given by (70). We have immediately from (177) and (178)

$$G(z_{22}/l_2 - y_{22}/l_2^2) - Wl_1(\phi_{11} - z_{11}/l_1 + y_{22}/l_2^2) + M_D(\phi_{11} + y_{22}/l_2^2) = o \quad (179)$$

This agrees with M_A given by (73).

To obtain δ_1 we notice from (176) that

$$\delta_1/l_1 = M_C(z_{11}/l_1) + (M_D - M_C)(y_{11}/l_1^2) = M_C(z_{11}/l_1) + Wl_1(y_{11}/l_1^2) \quad . \quad . \quad . \quad . \quad (180)$$

from which we find that

$$\delta_1 = -G(z_{22}/l_2 - y_{22}/l_2^2)z_{11}/(\phi_{11} + y_{22}/l_2^2) + W(\Delta_1 + y_{11}y_{22}/l_2^2)/(\phi_{11} + y_{22}/l_2^2) \quad (181)$$

REVIEW.

CARBURATION AND CARBURETTORS.

Charles H. Fisher. London, 1939. Messrs. Chapman and Hall, Ltd. 316 pp. with 132 Figs. Price 21/-.

Carburettors and their function have grown into a special and wide branch of engineering science since the times of the surface and wick carburettors, and hence the appearance of separate treatises and textbooks on carburation has become a necessity. This book gives a general and up-to-date, but restricted survey of the subject. It is not compiled from pamphlets of carburettor manufacturers as certain publications on the same subject which have already appeared.

The present book deals with the elements of carburation, fuels, mixture characteristics, carburettor operation, elementary hydraulics of the carburettor, the induction manifold, installation and road tuning and, finally, with a description of modern carburettor and mixture control types.

The book is restricted to motor car and motor boat and motor boat engines. It is written in a clear and instructive manner, dealing with the results of research work and with the practical problems. Though it does not refer to the intricacies of aero engine carburation, it may be well recommended for engineering students and craftsmen seeking information about the fundamentals of carburation.

THE ROYAL AERONAUTICAL SOCIETY

WITH WHICH IS INCORPORATED THE INSTITUTION OF AERONAUTICAL ENGINEERS.

MONTHLY NOTICES,

AUGUST, 1940.

New President.

Mr. Griffith Brewer, Honorary Fellow, has been elected the new President of the Society for 1940-1941 and takes office on October 1st, 1940.

Vice-Presidents.

Lieut.-Colonel J. T. C. Moore-Brabazon, M.C., F.R.Ae.S., M.P., and Professor L. Bairstow, C.B.E., F.R.S., F.R.Ae.S., have been elected Vice-Presidents for the year 1940-1941.

Society's Emergency Address.

It should be made clear that although the Society has published from time to time in the Journal its emergency address and telephone number (which can be used at any time alternatively with those of the Society), the Society functions, and has functioned from the beginning of the war, from No. 4, Hamilton Place, W.1. It will continue to function from London as far as possible, even though some of the staff may have to be moved, others will continue in London itself. It is obvious that events may make things difficult and cause a certain amount of delay, and members are asked to bear these events in mind.

The emergency address is—

Brook House,
Old School Lane,
Brockham, Surrey.

Telephone: Betchworth 189.

Election of Members.

The following Members were recently elected:—

Associate Fellows.—Thomas Edward Goligher (from Student), Albert Arthur Frederick Hickman, Arthur William Judge, James Norman.

Associates.—Eric Harry Banfield, Norman William Howard Freeman, Henry Richard William Frost, William Richard Gerard Harvey, Arthur Gordon Lee, John Love, Daniel Edgar Cuthbert Vaughan-Mallinson.

Graduates.—William Allison Hall Brown (from Student), Alan Breedon Malcolm Brush, Ivan Charles McOran Campbell, Alan John Clark, Donald Campbell MacPhail, Harold Moon, Charles Edward Onions, Douglas Ian Vickery (from Student), Geoffrey Light Wilde.

Students.—Peter David Doxford, James Michael Carol Kehoe, George Michael Scales, Alexander Zielony.

Companion.—Victor Frederick Beuttell.

Society of British Aircraft Constructors' Scholarships.

The Scholarship Selection Committee of the Society of British Aircraft Constructors and the Royal Aeronautical Society have made awards of Society of British Aircraft Constructors' Scholarships to the following:—

Charles Anthony Chapman, 3, Osborne Mansions, Luxborough Street, Marylebone, London, W. (Educated at University College School, Hampstead, and Maiden Erlegh School, near Reading.)

Joseph Charles Goodwin, Old Conduit House, Lyndhurst Terrace, Hampstead, London, N.W.3. (Educated at University College School, Hampstead.)

Peter Leland Bertram Graham, 63, Redcar Road, Guisbrough, North Yorkshire. (Educated at Faversham Grammar School, Dover County School, Guisbrough Grammar School.)

Hilary John Silvanus Pinsent, 24, Windermere Road, Babbacombe, Torquay. (Educated at Homelands Infants' School, Torquay; Westhill Council School, Torquay; Homelands Central School, Torquay.)

Geoffrey Donovan Poole, 28, Blenheim Road, Raynes Park, S.W.20. (Educated at Tiffin's Boys' Secondary School, Kingston-on-Thames.)

Peter William Wreford-Bush, West Hendford House, West Hendford, Yeovil, Somerset. (Educated at Geneva House School, Brondesbury; Brondesbury College; Tiffin's Boys' School, Kingston-on-Thames.)

The Scholarships are designed for the assistance of young men who are unable, for financial reasons, to take up a course of education fitting them to become aircraft engineers.

Candidates for scholarships had to be British Subjects between the ages of 16 and 18 on the 1st September in the year of the award.

A minimum of four scholarships a year of varying value up to a maximum value of £100 each per annum is awarded.

Scholarships are tenable with certain selected firms.

All holders of S.B.A.C. scholarships are expected to qualify for a technical grade in the Royal Aeronautical Society.

Entry forms and the general regulations for applying for one of these scholarships may be obtained from the Secretary.

Stanley Spooner Scholarship.

The late Stanley Spooner, the founder of *Flight* and its editor for so many years, left a sum of £5,000 to the Royal Aeronautical Society for the founding of a Stanley Spooner Scholarship for Aeronautical Research. The following is an extract from Mr. Spooner's will:—" . . . And subject thereto to set aside thereout a sum of five thousand pounds (free of duty) for the purpose of creating a 'Stanley Spooner Scholarship' for Aeronautical Research with the Royal Aeronautical Society, and I direct that all details in connection with the creation and maintenance of such Scholarship and with the eligibility for its enjoyment shall be arranged by my Trustee and the Fund shall be paid to or vested in such person or persons and in such manner as my Trustee in consultation with the Royal Aeronautical Society shall think proper."

The legacy does not become payable until the deaths of two life tenants of the amount under further provisions of Mr. Spooner's will.

Acknowledgments.

The Council acknowledge with grateful thanks the gift of back Journals and magazines from the following members:—Miss A. D. Betts, Companion; H. Parkinson, Associate Fellow; Mr. G. C. D. Russell, Associate Fellow; Mr. T. S. Lofthouse, Associate.

The Council would also like to acknowledge the gift of a translation from the French of " L'Empire de L'Air," translated by Major Jullerot and General Caddell, and presented to the Library. The original French copy of " L'Empire de L'Air " was presented by Major Jullerot some time ago, who also kindly presented a sequel to " L'Empire de L'Air," " Le vol sans battement."

Additions to the Library.

B.a.100.—Aeroplane " Jona 6-S " (Motore Alfa D2, C.30). Ministero dell'Aeronautica, Rome. 1939.

B.a.101 and 102/Y.3.ii.J.—L'Avion d'Ecole et Entrainement " Jona 6-S." Piero Magni, Milan. (Undated.) Two copies.

B.a.103/Y.3.ii.G.—British Aeroplanes of 1938: Dimensions, Weights, Performances. " The Aeroplane." 1938.

B.e.32.—Scale Model Aircraft. By James H. Stevens. John Hamilton, Ltd. 1933. 5/-.

B.e.33.—The Design and Construction of Flying Model Aircraft. (2nd Edition.) By D. A. Russell. Harborough Publishing Co. 1940. 6/6.

**B.f.38.—Le Vol sans Battement. By L. P. Mouillard. (With Preface: " L'Oeuvre Ignorée de L. P. Mouillard," by A. Henry-Couannier.) Per Orbem, Paris. 1923. Frs. 15.

*B.g.84/PB.5/11.—Recognition Tests. (What are They?) " The Aeroplane." 1940. 6d.

D.b.127/Y.6.b.la.—Die Vergrösserung der Flugzeuge. (Photostat of Lecture.) By Adolf Rohrbach. 1921.

D.e.25/PD.3.c.2.—Aviazione da Trasporto ad Alta Velocità. By Alberto Jona. Istituto Poligrafico dello Stato, Rome. 1934.

E.f.64.—Aircraft Maintenance. By D. J. Brimm and H. E. Boggess. Sir Isaac Pitman. 1940. 10/6.

EE.b.52/Y.7.d.G.—British Aero-Motors of 1938. " The Aeroplane." 1938.

*G.b.3.—British Standard Specifications:—

D.34.—Ethylene Glycol for Aircraft Purposes.

2F.55.—Cotton Duck (Dyed) for Cases and Travelling Bags for Parachutes.

British Standards Institution. 1940 (1/- each.)

G.b.30/PG.2/14.—British Standard Specification No. 904. Dimensions of Instrument Jewels. British Standards Institution. 1940. 2/-.

J.g.52/Y.30.i.—The 11-Year and 27-Day Solar Periods in Meteorology. By H. Helm Clayton. Smithsonian Institution, Washington. 1940.

K.a.12/Y.14.b.2.—The Distribution of Temperature in the Lower Stratosphere. By M. W. Chiplonkar. Indian Academy of Sciences. 1940.

L.c.16.—Through the Overcast. By Assen Jordanoff. Funk and Wagnalls 1938. 12/6. (2nd Copy.)

L.d.55.—The Complete Air Navigator. By D. C. T. Bennett. (2nd Edition.) Sir Isaac Pitman. 1940. 15/-.

**Q.a.128.—Aerostation. (Catalogue No. 685.) Maggs Bros., Ltd. 1940.

Q.b.58.—National Central Library. 24th Annual Report of the Executive Committee. 1940.

S.a.108.—Recollections of an Airman. By Lt.-Col. L. A. Strange. John Hamilton, Ltd. 1935. 3/6.

*V.1/20.—Transactions of the American Society of Mechanical Engineers. Vol. 61. 1939.

Also the following works, bequeathed from the Library of the late Mr. Stanley Spooner:—

**R.f.55.—21st Anniversary of " Flight," 1909-1930. (Bound Volume with Menu of Celebration Dinner, Autographs of Guests, Letters and Telegrams of Congratulation, etc.) 1930.

**TT.c.7.—Aeronautical Prints and Drawings. By W. Lockwood Marsh. Halton and Truscott Smith. 1924. £3 3s. 0d.

**B.a.183.—Napier Aero Engines. D. Napier and Sons. 1924. £1 1s. 0d.

**BB.e.24.—The Birthplace of Aerial Power. (History of the Grahame-White Company.) Grahame-White Co., Ltd. 1919.

**B.f.62a.—L'Empire de l'Air. (Translation from the French, with Appendix.)

RR.104.—Principles of Flight. By A. E. Berriman. Flight Publishing Co. 1913. 2/-.

**Z.g.1.—Autographed Luncheon and Dinner Menus (from 1914-1929).

**TT.c.8.—Special Mail Stamps, Commemorating Sir Alan Cobham's Flight from London to Cape Town. 1925. (Sheets of stamps, some perforated and others unperforated.)

EE.b.54.—Report on Design of Newman "Meteor" Engine. (Report No. 986.) Ricardo and Co., Ltd. 1933.

**R.d.29.—Souvenir of Pemberton-Billing "Supermarine" Works. (Photographs mounted on silk ribbon.) Undated. (About 1918.)

Z.b.38.—Souvenir of International Aero Exhibition, Olympia, July 16-17, 1929.

* or ** Books marked thus are not available for loan.

The following books are missing from Library (second list):—

Nadaud, M. The Flying Poilu. 1918.
P.I.X. The Spider Web: the Romance of a Flying-Boat War Flight. 1919.
Reid, A. C. Planes and Personalities: A Pot-Pourri. 1920.
Samways, G. R. Ballads of the Flying Corps. 1917.
Studley, Barrett. Practical Flight Training. 1928.
Sullivan, Mark. America Finding Herself. 1927.
Stephenson, W. T. Resources of the Empire: Communications. 1924.
Sykes, Sir F. H. Aviation in Peace and War. 1922.
Turner, S. (and H. B. Gray). Eclipse or Empire? 1916.
Turner, C. C. The Struggle in the Air. 1919.
Smith, C. E. Kingsford- and Ulm, C. T. P. The Story of the Southern Cross. 1929.
White, T. W. Guests of the Unspeakable. 1928.
Woodhouse, H. Text-Book of Military Aeronautics. 1918.
Younger, J. E., and Ward, N. F. Airplane Construction and Repair. 1931.

J. LAURENCE PRITCHARD, *Secretary and Editor.*

The 650th Lecture read before the Royal Aeronautical Society since its foundation on January 12th, 1866.

PROCEEDINGS.

A meeting of the Royal Aeronautical Society was held in the Lecture Theatre of the Institution of Electrical Engineers, at Savoy Place, Victoria Embankment, London, W.C.2, on Friday, April 19th, 1940, when a paper on " Some Aspects of the Aerial Warfare in the German-Polish Campaign," by Mr. J. J. Dziewonski and Mr. S. Rogalski, was read and discussed.

In the chair, Lord Sempill (Past-President of the Society).

The CHAIRMAN: He first extended a hearty welcome, on behalf of the Society, to the many guests who were present to hear the reading of so interesting a paper, contributed jointly by two distinguished Polish aeronautical engineers.

Introducing the authors formally to the meeting, the Chairman said that Mr. Dziewonski was a Graduate of the Department of Mechanical Engineering at Warsaw, and had held a number of very important positions. For the Research Institute for Aeronautics he had served as Research Engineer at the Aero Testing and Development Station, dealing specially with fuels and lubricants. Then at the National Engineering Works in Warsaw he was in charge of the Aero Engine Department in the capacity of Production Manager. Later he had served at the Engine Factory of the P.Z.L. National Aircraft Works at Rzeszow in the capacity of Technical and Vice Director; and he was at the factory at Rzeszow until the middle of September, 1939, when he had received orders to evacuate that position.

Mr. Rogalski, who was also a Diploma Engineer, had graduated at the Department of Mechanical Engineering in the Warsaw Polytechnic, and had since held a number of important positions. He was Lecturer on Aerodynamics at the Lemberg Polytechnic, Assistant Professor of Applied Aerodynamics at the Warsaw Polytechnic, and lastly, was Designer for the R.W.D. Company, which produced the winners of the 1932 and 1934 Challenge—the R.W.D.6 and R.W.D.9 touring planes, fitted with British and Polish engines respectively.

Mr. DZIEWONSKI: Mr. Rogalski and himself counted it a great privilege to address so distinguished an audience, and he expressed their thanks to Mr. Fedden, the President of the Royal Aeronautical Society, for his kind invitation to them to present the paper.

SOME ASPECTS OF THE AERIAL WARFARE IN THE GERMAN-POLISH CAMPAIGN.

By J. J. DZIEWONSKI and S. ROGALSKI.

This lecture is an attempt to give a brief survey of some facts observed during the German-Polish campaign, which are thought to be of interest to the aircraft industry. The authors wish to stress that they fully realise the scarcity of actual data on which any possible conclusions could be based. There is no doubt that a " Blitzkrieg " provides all of the experience to the winner, particularly if he enjoys an overwhelming superiority in the air and has secured a " total " victory, as was the case in this campaign. His vision was clear and far-reaching, his striking arm able to inflict blows, wherever required by tactical considerations. He was able to investigate closely on the spot damage done by his weapons, at the end of hostilities. One conclusion, seems to be obvious, and it

is that the advent of modern mechanised ground and air forces has greatly endangered the position of the smaller nations.

The equipment of an Air Force is, in the first instance, dependent on considerations of the strategic position of a particular country and her potential adversaries. It is, therefore, considered to be of interest to give a brief survey of Poland's geographic position, natural resources and industry.

From the strategic point of view the position of Poland may be considered to be one of the worst, if not actually the worst, in Europe. In the first place that country is placed between two large and potentially hostile countries. The length of her land frontiers, about 3,500 miles, almost completely devoid of any natural defences, makes the construction of any kind of artificial defence line an impracticable proposition. Only the Carpathian mountains in the south and the marshy region of Pinsk in the central East could be considered as having military defensive value. Germany, on the other hand, had a vast military camp with a number of Air Force camps in Eastern Prussia, lavishly protected by nature in the way of

Messerschmidt Me 109.

lakes, rivers and forests. Flatness of the country makes it ideally suited for quick operations of modern mechanised ground troops. In case of war with her Western neighbour, Poland could look only to the Vistula, San and Bug rivers as her ultimate lines of defence. As to communication with the outside world, there was her south-eastern frontier with Roumania left for this purpose, the whole length of the Carpathians being devoid of railways and roads across the mountains, and the way to her sea coast being untenable because of the narrow neck in Pomorze, between Germany and East Prussia.

The vital industrial centres, coal mines, iron ore, steel plants, etc., are all located in and near around Upper Silesia, close to the German frontier. The weakness of this situation was sought to be remedied by the development of new centres of industrial activity in the so-called C.O.P., or Central Industrial District, in the fork between the rivers Vistula and San and around it. This district, though possessing a few large industrial plants, existing there before the Great War, has always been considered an agricultural one. A number of modern plants had been completed or under construction in this district just before the present war.

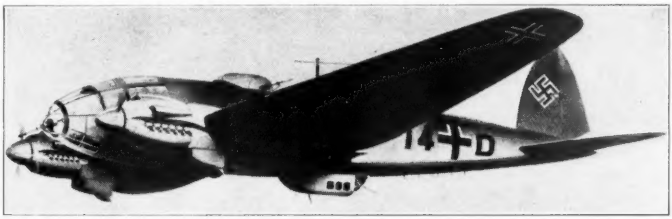
The principal natural resources, important from the military point of view, are as follows:—

Coal, estimated resources	158,000,000,000 tons
,, yearly production	35,000,000 ,,
Steel production	1,500,000 ,,
Zinc production	100,000 ,,
Lead production	18,000 ,,
Crude oil production	500,000 ,,

It may be noted, in reference to the crude oil production, that the yield of the oil wells was on the decline, the peak year being 1929. The capacity of the refining plants, which amounted to about 1,200,000 tons yearly, was exploited to about only 45 per cent. On the average a petrol of about 63 to 65 octane number was obtained. This property and the insufficient output was the reason for the use of the petrol-alcohol-benzol blends for the preparation of the standard basic fuel of 73 to 75 octane value, from which a fuel of 87 octane number was obtained by the addition of tetra ethyl lead, di-isopropyl ether was also used as a knock suppressor.

For a rough approximation it may be assumed that Silesia was responsible for all of the steel and iron production forgings, bars, tubes, sheets, etc., as well as practically for all of the zinc, lead production and copper and light alloys manufacture.

C.O.P., the new industrial district, was under development with large steel and heavy armament works, synthetic rubber, cellulose, explosives, ammonia plants, etc., as well as two air frame and aero engine plants.



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Production of machine tools, railway equipment, etc., was concentrated in Silesia, Poznan, Warsaw, Radom, Kielce and Krakow districts. The textile industry being greatly developed in the Lodz and Bialystok areas.

It is beyond the scope of this lecture to go any further into the subject of industrial development of pre-war Poland, but some more details of that country's aircraft industry may be of interest.

Aircraft Industry in Poland.

The aircraft industry is concentrated in Warsaw, Lublin, Biala Podlaska, Rzeszow and Mielec, comprising the following air frame and engine plants.

Frame Plants.

1. P.Z.L., or National Aircraft Works, which included two airframe factories in Warsaw and Mielec, and two engine factories in Warsaw and Rzeszow. Both of the frame factories were engaged in the production of all-metal service aircraft of their own design. The types produced included, amongst others, the following:—

Los, twin-engine bomber.
P11, single-seater fighter.
P7, ditto.
Karas, Army co-operation plane.
Sum, ditto.
Wilk, light attack bomber.
Jastrzab, single-seater fighter.

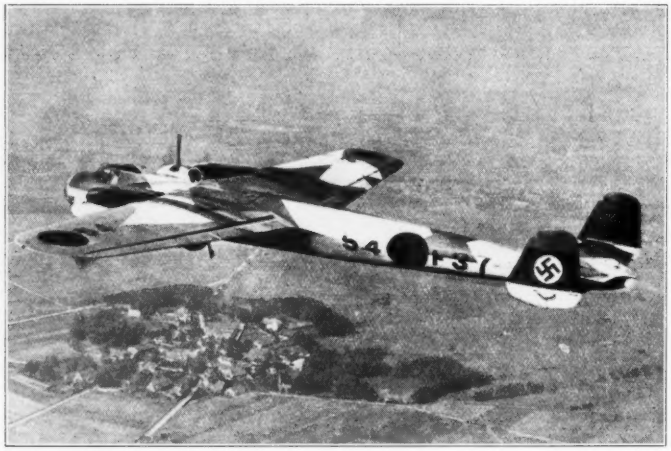
A number of these fighters and some of the Los type bombers have been sold to Turkey, Yugoslavia, Greece, Roumania and Bulgaria.

2. Lubelska Aircraft Factory in Lublin, was making mixed construction service aircraft of their own construction. The machines produced were as follows:—

Mewa, Army co-operation aircraft.
RXIII, ditto.

3. P.W.S. aircraft factory, in Biala Podlaska, was concentrating on the manufacture of training aircraft of the mixed construction type, mainly designed and developed by the P.Z.L. or R.W.D. companies. They had also made a number of Avro trainers under licence arrangements with the A. V. Roe Company of this country.

4. R.W.D. aircraft factory, in Warsaw, was making training, touring and service aircraft of their own design. This company was well known in aviation circles in 1933 and 1934, when their type R.W.D. 6 and R.W.D. 9 touring planes won the Challenge International de Tourisme Aerienne in close competition with German machines.



Dornier Do 17.

Besides these plants there was a small glider factory in Lwow, which was of no military value.

The aero engine industry included the following plants:—

1. P.Z.L. factory No. 1, in Warsaw, was engaged in the production of poppet valve engines of the Pegasus and Mercury types, under licence arrangements with the Bristol Aeroplane Company, besides making smaller engines of their own design, which included the following:—

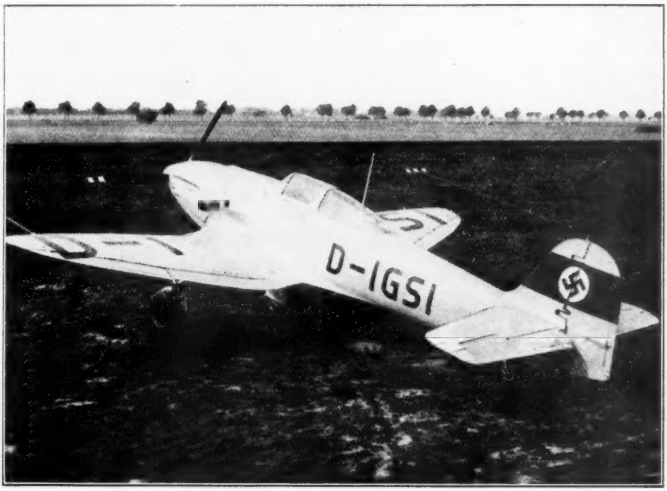
Mors, nine-cylinder radial of 450 h.p. at 3,000 ft.
Foka, eight-cylinder inverted V of 350 h.p. at 6,000 ft.
GR 760, seven-cylinder radial of 260 h.p. at sea level.

This factory was preparing to start production of constant speed propellers under licence arrangements with the Hamilton Airscrew Co., of U.S., and in collaboration with the de Havilland Co.

2. P.Z.L. factory No. 2, in Rzeszow, was a completely new plant, built under the C.O.P. development scheme. Foundations of some of the buildings had been laid down in the autumn of 1937. Because of many difficulties and delays in the supply of machine tools, production could not have been started before the autumn of 1938. It may be pointed out, in this instance, that contrary to the practice of countries with well developed industries, precision production plants

in Poland had to make jigs, tools and gauges at their own shops. This applied to the aircraft and armament industries as well. The Warsaw and Rzeszow plants had, consequently, rather large tool and jig shops, the Rzeszow plant being, for example, equipped with some 125 machine tools, producing all the special jigs, tools and gauges for the production of Pegasus and Mercury engines, besides making standard tools and gauges for its own production and for outside customers. The large government controlled concern P.W.U., or National Armament Works, had a large central tool and gauge shop, where all sorts of standard precision measurement equipment, including gauge blocks, were made.

3. Avia Precision Works, in Warsaw, was manufacturing aero engines under licence arrangements with P.Z.L. and the Gnome and Rhone Company, of France, besides making retractable undercarriages, inertia starters, and similar equipment for aircraft.



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4. P.Z.Inz. or National Engineering Works, in Warsaw, mainly engaged on the manufacture of automotive service equipment, had an aero engine department, which was manufacturing small inverted in-line engines for touring and training aircraft.

These factories were aided and supplemented by a number of sub-contracting works, producing aero engine and aircraft equipment, including carburettors, magnetos, sparking plugs, fuel pumps, piston rings, etc. Most of these plants were newly established ones, and were in the course of gaining the necessary manufacturing experience, though some of them had already been able to sell manufacturing rights to foreign countries for devices developed by themselves. Wooden airscrews had been made by a Warsaw factory.

In closing this brief summary it may be of interest to point out some of the difficulties that had been encountered in starting the new plants during 1938 and 1939, when the C.O.P. plants came into being and the productive capacity of the aircraft industry was about to be doubled. The major one was scarcity of trained labour. This question has been faced by the Allies. It will remain an important one in all future conflicts as it is impossible to visualise any country, even one with a highly developed industry, being able to find employment in

peace time for the number of men and women, indispensable during war time expansion of industry.

This subject has been dealt with in the Rzeszow plant in the way of organising special training courses for two classes of men. One of these was to give as much practical shop experience in as short as possible time to men, or rather boys, with previous training at trade schools, the object being to train them for work on the more delicate jobs, as operators, fitters, tool makers, viewers, inspectors, etc. They were given practical instruction on machining, tools, methods of measurements, and attended classes where lectures on factory organisation, drawing reading, shop arithmetics, properties of materials from the point of their machineability and geometry were given. The course lasted five months, after which all candidates were submitted to a theoretical as well as to a practical examination. As the number of men at the shops was not sufficient for the production required, these boys started actual working in the shops after only two weeks of preliminary training. They were paid the standard rates, but without bonus. After having passed their examinations, they were shifted into the next higher class of pay rate and were allowed bonus. The average age of the boys was about 18 years, and they proved to give valuable work in a short time.

P.Z.L. Sum.

As the number of candidates with suitable training was greatly below what was required, it was necessary to find some means of using those without any previous training or experience in this type of work. For these, special short classes were organised with the object of providing a number of men suitable to be operators of machine tools where skill is not required. Candidates attended classes and had practical training on a number of machine tools, specially assigned for this purpose, in groups of thirty men each. The duration of the course was only six weeks, after which the men started working in the machine shop on simple operations under close supervision of experienced operators and foremen, whose number, it possibly should be stated, was far from being sufficient.

Some Examples of Industrial Plants Working Under Actual War Conditions.

The following provisions were made for the protection of industrial plants and in order to enable their working in war time to be carried on.

Each plant was protected by two to four A.A. guns of the 40 mm. Bofors type or 75 mm. guns, and a number of machine guns, located on the roofs of

the factory building or camouflaged near the plant. This armament was manned by factory personnel, who had undergone special training under the supervision of military authorities. In the light of the experience, however short and incomplete, such protection should be considered as being inadequate, not only as to its equipment and power of fire, but as to its principle as well. An increase in number, calibre and diversity, while tending to increase the risks and casualties of the enemy, would not prevent a determined bombing force from doing its destructive work. Manning the guns by factory personnel does not seem to be the best solution, as these neither have the necessary training and experience, nor can they be expected to perform their duties in the shops in case of emergency.

For the protection of men during air raids, trenches were dug outside the factory premises, but close to its gates. This also did not prove to be an efficient way of protecting the personnel, especially when raid warnings were sounded on sight of the approaching aircraft.

Conditions in the Warsaw P.Z.L. plants and in Rzeszow during the few days of war will be now reviewed briefly.

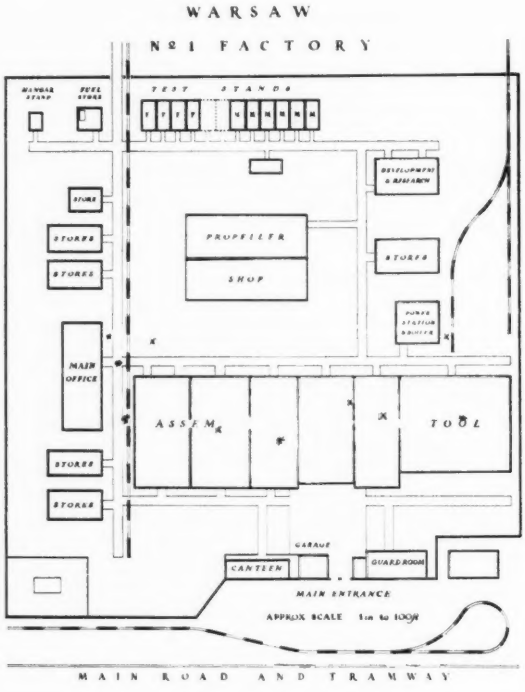
The Warsaw factories, frame and engine, are situated on the eastern and western outskirts, respectively, of the civil and military airport, over which the German reconnaissance and bombing machines made their first appearance at about 7.30 a.m. on September 1st, a few hours after the outbreak of the undeclared war. After that air raids were carried on, several times in the day, from about 6.0 a.m. till about 6.0 p.m., each bombardment being followed by observation planes, coming to take pictures. The marksmanship was, at the beginning, not very good, but improved quickly. The generally clear weather with some clouds, that prevailed during the whole of September over Poland greatly aided the attacking air force.

The first three bombs that fell on airframe factory No. 1, out of over one hundred dropped all around, at about 4.30 p.m. during the fourth air raid on September 1st, did little material damage. One bomb hit the canteen and exploded in its basement, killing three men and wounding several. The other exploded near the development department building, blowing out almost all of that building's windows, seriously disorganising the working of the drawing records and printing departments, located there.

It had been decided by the management to continue working in two shifts, but on the next morning only about 60 per cent. of the workers appeared. This, however, was accounted for by the disorganisation in railway transport and damage done to Warsaw suburbs, bombed on the previous day, where the majority of workers had their dwellings. There was little organised work on that day in the factory, though no bombs were dropped. On September 3rd, during the sixth consecutive raid on that day, some hundred heavy bombs were dropped, three of which hit the main building, two of them exploding and considerably damaging the machine shop and equipment. The factory had been ordered to evacuate its equipment to small shops in town. On this day the whole of the Warsaw aerodrome was heavily bombed, and considerable damage done to the Air Force hangars, landing field and railway branch line leading to the airframe factory. Warsaw suburbs were also heavily bombed and many fires occurred. On September 4th P.Z.L. airframe factory ceased practically to exist after severe bombing, during which dive bombing with Ju 87 bombers had been carried on and many fires started. It should be noted that actual work had been practically stopped on the second day, because of frequent evacuation of personnel to the trenches on approach of enemy aircraft.

The course of events in the engine factory in Warsaw differed but little from the above, and though this factory had been first bombed on September 4th, its production must have fallen sharply, owing to frequent raids and consequent loss of time during evacuation of personnel and disorganisation. The plant came to a standstill on September 4th, when about 5.30 p.m. a raid was carried out by

some 25 bombers. Out of some one hundred bombs of the heaviest calibre, four fell on the factory premises, as shown on the slide. These were dropped by Ju 87 dive bombers. Material damage done by the large bombs falling in the main building was considerable. One of the bombs destroyed the jig and tool store located in the centre of the building, the other destroying a number of machine tools in the jig and tool shop. A number of smaller explosive and incendiary bombs were also dropped, hitting the main building and starting fires. Difficulty was experienced in extinguishing these fires, as the water mains leading to the factory were damaged. Several people were killed during this raid.



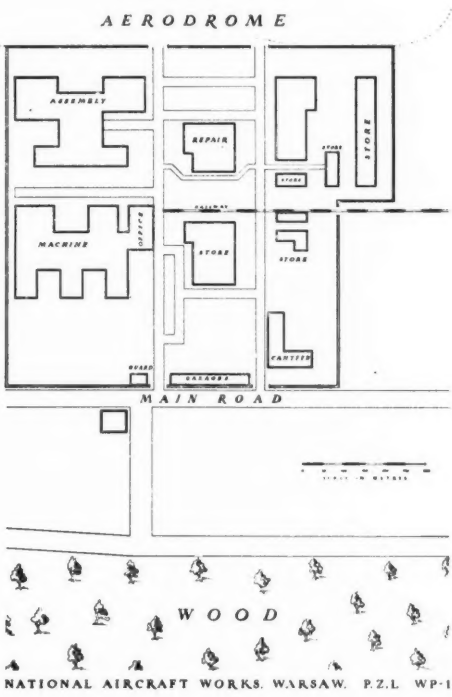
× *indicates where bombs fell.*

Things went slightly different at the Rzeszow plant. That factory and her neighbour, the Cegielski Armament Factory, which, incidentally, supplied a number of A.A. Bofors guns to Great Britain, were protected in the same manner as other plants, *i.e.*, completely inadequately, but the plant was working till September 6th, when her supply of electric current from Moscice power station was cut off by the Germans, and orders were received from the Army Command to destroy the machinery and equipment and to evacuate the personnel.

Its work had only been possible because that factory, for some reason or another, had not been chosen as a target for six days by the German Air Force. Five bombs were, however, dropped on September 6th at about 5 p.m., only one of the bombs hitting the assembly shop. That bomb, though making a crater of some 25 feet in diameter and some 8 to 10 feet deep, left all the windows in the building intact.

In order to be able to carry the work on in the shops in spite of very frequent disorganisation, it had been necessary to abandon the day shift and to resort to

a night one of ten hours, not only for the shop but for all office work as well. Only a small shift, that could be herded in the factory main bomb proof shelter, was left for the day. This scheme worked quite smoothly, and all nervousness on the part of the personnel, that was felt on the first two days, gradually faded. There was one drawback in this scheme, however, and that was the difficulty of having a few hours' rest during the day time, under conditions of frequent air raids and A.A. fire. The whole works were, of course, completely blacked out, a measure not quite justified by the course of events as the German command did not consider it worth while to take the unnecessary risks of night flight, under prevailing conditions of almost unchallenged superiority in the air. In order to be able to cope with blown windows, the area of which was about two acres, an appropriate quantity of thin gauge sheet iron had been ordered to replace window glass.



NATIONAL AIRCRAFT WORKS. WARSAW. P.Z.L. WP-1

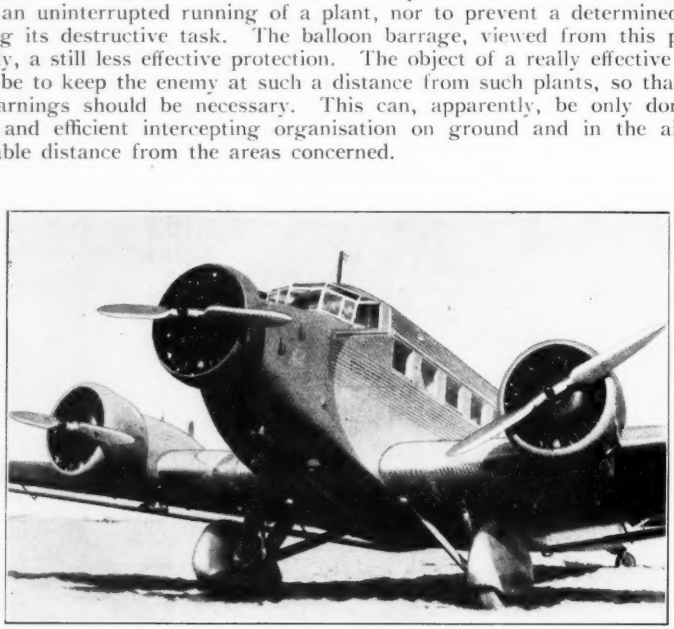
As already stated, the marksmanship of the German bombers in areas with more or less efficient protection was not very high, though improving quickly with experience gained. Some remarkably good marksmanship was, however, displayed on bombing railways and trains, which, of course, was more like practice bombing. Dive bombing was much more effective even in protected areas.

Observation of events at these three plants, however incomplete, still allows some conclusions to be drawn.

First of all, it appears that a high precision production plant, such as an aero engine factory, can be easily upset by comparatively little material damage, owing to its complexity and dependence on a large amount of special equipment in the form of jigs, tools and gauges, as well as heat treatment furnaces and similar equipment, not readily obtainable on the market.

Even without actual damage, through frequent raids only, its normal functioning and output is greatly hampered. The evacuation of personnel at every air raid seems to be an essential form of precaution, and the consequent interruption of work is not only confined to the duration of the air raid plus the time to take shelter and return to work, but is in practice much longer.

The second conclusion, based on the consideration of the first one, is that local protection by artillery and machine guns, however strong and diversified to cope with different forms of attacking craft and their tactics, can only at its best, increase the risks and casualties of the enemy, but will not be able either to ensure an uninterrupted running of a plant, nor to prevent a determined enemy of doing its destructive task. The balloon barrage, viewed from this point is, probably, a still less effective protection. The object of a really effective defence should be to keep the enemy at such a distance from such plants, so that no air raid warnings should be necessary. This can, apparently, be only done by a strong and efficient intercepting organisation on ground and in the air, at a reasonable distance from the areas concerned.



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POSSIBLE FORMS OF ORGANISATION OF INDUSTRIAL PLANTS OF MILITARY IMPORTANCE.

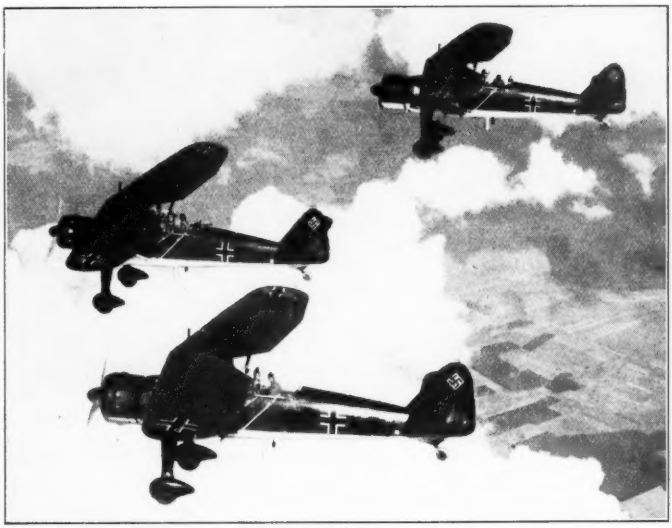
Developments in the equipment of modern armies, on land, sea and in the air, have been such that it is inconceivable to have a war conducted with equipment, manufactured and stored in peace time, unless the disparity in numerical strength is such as to promise a " Blitzkrieg " result. This is, in the first instance, true of the Air Force, because of incessant and quick development in equipment and the difficulty of storage of large quantities of aircraft. It is, therefore, necessary to have an industry capable of giving a greatly increased output in time of emergency and at short notice. This means that these potential plants should be capable of working smoothly under actual war conditions, which can be achieved by removing them beyond the range of enemy bombs, either in the way of hiding them in some really efficient manner, or locating them in places not easily accessible to bombers.

The following seem to be reasonable possibilities to be worth consideration:—

1. Sub-division of large plants into a number of smaller units, concentrating on the production of parts and sub-assemblies. These subsidiary units should be

possibly duplicated so that the destruction of one of them would not upset the whole production. It will be probably necessary for these plants to have their most important and vulnerable departments and equipment protected in such a manner as to ensure their working even under air raid conditions. Heat-treating department equipment and jig and tool stores, containing duplicates of the special outfit not readily obtained on the market, should fall into this category. Generally speaking, production departments are much more vulnerable than assembly and testing in case of engine production. This form of industrial organisation has, however, the drawback of greatly enlarging the area to be protected, besides presenting a number of difficulties in the production field. Wide experience in this field should have been accumulated in this country, and it would be of great interest to learn the opinion of the organisations concerned, when such data are no longer considered confidential.

2. A probably more efficient, but much costlier scheme is to conceal complete factories, particularly those designed specifically for working in time of emergency, under ground, or at least laying them out as many storied buildings, with the more important departments located under ground and protected by a number of bomb proof ceilings.



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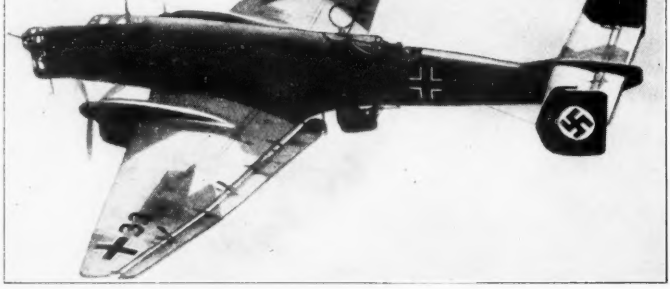
3. The third scheme would entail the removal of whole factories to places outside the range of enemy bombers. This can be only considered by nations having suitable possessions with a supply of basic raw materials and would necessitate the development of an industry to convert these into semi-fabricated products. One may venture to express the opinion that, however this plan may seem to be unpractical at present, it may play an important part in the future, in a much wider field than that of purely strategical organisation of war industry.

AIR FORCE OPERATIONS.

Air force operations have undoubtedly played an important part in bringing the speedy and complete victory to the German Command in the Polish campaign of this war.

The numerical superiority of their Luftwaffe was so overwhelming that what was left of the Polish Air Force, after the surprise attack on the early morning of September 1st, could not be expected to bear appreciably on the issue of the campaign. The only, though bitter, consolation is that its results cannot be regarded as a proof of the quality and efficiency of the German air force.

The German tactics were to strike at as many airport stations and landing fields, known to exist in Poland, on the first morning of the undeclared war, and thus destroy on the spot the units of the Polish Air Force. This was generally carried out as a surprise attack from low altitude. Bombing with explosive and incendiary bombs and machine gun fire were extensively used. The damage inflicted was in some places heavy, in others slight. The marksmanship on the average was poor. The effect on the morale of the troops and civil population must, however, be considered to have been great. Railway centres and lines were also bombed at many points, upsetting to a great extent the mobilisation of the Polish army, and practically preventing its completion. Vital industrial plants, mostly those located far inside the country, were raided and bombed. Their work was upset and the rate of production fell sharply in conse-



Junkers 86

quence of incessant raids. German bombers were observed bombing apparently empty roads inside the country, thus not only destroying these, but telephone and telegraph lines running along them. It was not a question of concentrated raids on some of the military important centres, but a powerful attack on the whole of the strategic organisation of the country, which prepared a consequently comparatively easy invasion for the ground forces.

The constant presence of the Luftwaffe over Poland was of very great advantage to the German High Command, without which it would have been much more difficult for them to achieve the speedy victory.

AIRCRAFT INVOLVED IN THE HOSTILITIES.

Polish Air Force:—

Fighters: P.Z.L. P11, and P7, numbering 240.

Bombers: P.Z.L. Los, numbering 100, of which about 40 were destroyed on the ground on the first day.

Light bombers: P.Z.L. Karas, numbering 180.

Reconnaissance and army co-operation R.W.D. Czapla, numbering 60.

FIGHTERS.

The P.Z.L. P11 fighters, a development of the P7 type of 1931 design, should be considered as an obsolete equipment as compared with modern machines of the same class of the Luftwaffe, both as to their performance and armament. It is astonishing that, in spite of this, they were able to contact, fight and even shoot down a number of German bombers and even fighters of the Me 109 class, when these were imprudent enough to accept a fight instead of simply sneaking away, which they easily could do owing to their much superior speed. The P11 fighters could do this, of course, only when encountering the German machines under favourable circumstances, enabling them to gain speed through a dive. The successes of these fighters, some of which had up to eight hours daily in the air to their credit, must be, in the first instance, attributed to their high degree of manœuvrability and comparatively high rate of climb. The following comparative figures of P11 and Me 109 fighters may be of interest:—

Performance.	P11.	Me 109.
Rate of climb	2,490 ft./min.	3,396 ft./min.
Radius of narrowest turn ...	393 ft.	585 to 860 ft.
Time of a complete turn ...	14.5 sec.	18 to 24 sec.
Top speed	220 m.p.h. at 13,000 ft.	356 m.p.h. at 12,500 ft.

The performance figures of the P11 are actual ones, those of the Me 109 are taken from literature and partly figured out.

P.Z.L. P XXIV F.

BOMBERS.

The P.Z.L. Los bombers suffered severe losses on the ground on the first morning of war. They had been used against enemy armoured forces, attacking from an altitude of 6,000 to 8,000 ft., which is above the range of light field A.A. artillery, accompanying those units. Owing to their good manœuvrability their losses in action did not exceed 20 per cent., while successful attacks

were carried on standing massed tank units. The losses in the P.Z.L. Karas light bombers were much heavier, which should be attributed to their low speed. These bombers, of 1935 design, were also used against ground armoured forces. In encounters with German Me 109 fighters, they succeeded on several occasions in bringing these down.

Army Co-operation and Reconnaissance Aircraft.

The small number of these aircraft and the generally prevailing conditions did not give much opportunity for them to operate as army co-operation. They were, however, busy as reconnaissance and liaison aircraft for the Polish High Command. Losses in this class in the air were small.

It may be generally accepted that the majority of all class of Polish aircraft were lost on the ground through enemy air force action. Only a limited number can be attributed to action in the air and to A.A. artillery, for some of which our own A.A. artillery was responsible. Owing to speedy German advance and quick destruction of emergency landing fields by their air force, it was necessary to remove these farther to the east, where means of communication were scarce and lack of adequate ground organisation finally put out of action, what remained of the Polish Air Force.

P.Z.L. Mewa.

Only little experience has been gained as to behaviour of aircraft and engines under severe field conditions, without any servicing practically. A large proportion of the engines had to be overhauled just before the war, having completed the prescribed number of hours. Yet, and in spite of the fact of running the Mercury V and Pegasus engines at much higher boost than the rated, there have been no cases of engine breakdown reported. The same can also be said of the aircraft. Dry weather that prevailed during the whole of September and the consequent dust on emergency landing fields did not tend to make things easier. Servicing was made very difficult by incessant changes of landing fields. There were several occasions when emergency fields had to be abandoned after only one night, in consequence of their discovery and subsequent bombing by the German Air Force. Thus a landing field of a squadron of Karas bombers has been spotted at dusk by the Germans and bombed at sunrise on the next morning. Two machines were destroyed by fire and seven severely damaged.

German Aircraft.

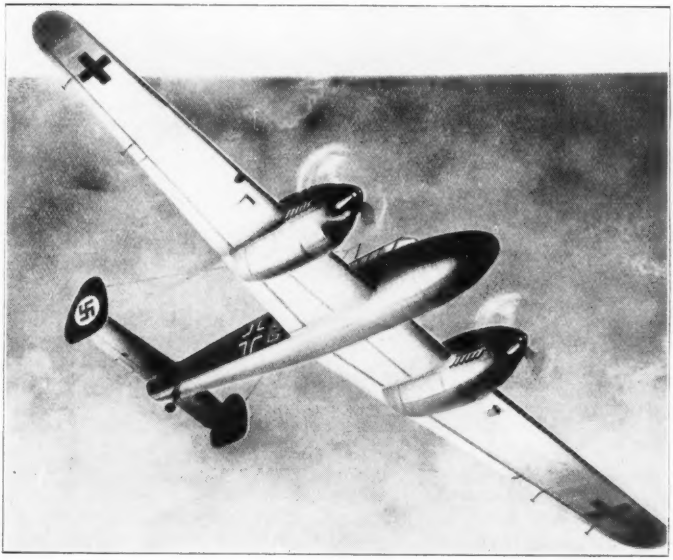
The number of German aircraft engaged and their losses in the Polish campaign are, so far, unknown. From reports on the number of aircraft observed flying daily over various parts of Polish territory, it may be assumed that the number was near around 2,000. The following machines are known to have taken active part in the Polish campaign:—

Bombers:
Junkers Ju 52.
Junkers Ju 86.
Heinkel He 111.
Dornier Do 17 and Do 215.

Dive Bombers:
Junkers Ju 87.
Henschel Hs 123.

Fighters:
Heinkel He 112.
Messerschmidt Me 109 and Me 110.

Army Co-operation and Reconnaissance:
Henschel Hs 126.
Fieseler Storch.



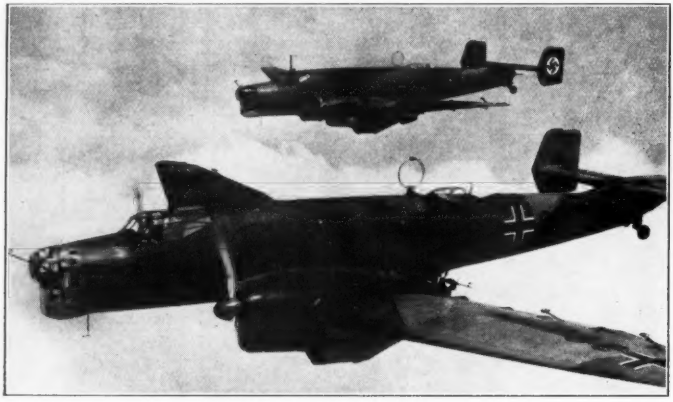
Messerschmidt 110.

All of these machines are well known and hardly need any description. They are all of a modern design. The first line aircraft are distinguished by their high speed and lower manœuvrability as compared with Polish ones, of which only the Los could be regarded as a really modern machine. Their much heavier armament made them formidable opponents.

German bombers, with the exception of their first day attack, when they came at a low altitude, usually appeared over protected areas at an altitude above the range of the A.A. defences. Their shooting was not of the highest precision at first, as, for example, during the bombing of P.Z.L. Warsaw factory, when, out of about 200 bombs, only three fell inside the works premises. Later on, their marksmanship, as well as that of our A.A. batteries, increased quickly. When, however, definite results had to be obtained, dive bombers were usually resorted to. Thus, both of the Warsaw P.Z.L. factories were destroyed by Ju 87 dive bombers, which were also extensively used for bombing of Lwow and other railway centres. Besides the Ju 87, the Henschel Hs 123 dive bombers were used

to attack the fortifications on the Hel peninsula, and in Modlin, near Warsaw. To deceive the A.A. batteries, the following tactics were reported to be used:—A formation of five aircraft, of which two were dive bombers, flew over the object at an altitude near the ceiling of the batteries. Then the dive bombers suddenly broke off the formation, starting their dive attack. From the ground it seemed as though these were hit, and the batteries concentrated their fire on the level flying craft, thus enabling the dive bombers to do their work. The Ju 87 and Hs 123 can be credited with a high degree of manœuvrability, which in addition to the Ju 87 rear gunner made them redoubtable opponents for the Polish fighters. They usually made their escape, after releasing their bomb load, flying at low altitude, and eventually zig-zagging where ground defences were to be feared.

On their first approach to areas known to be protected by fighters, German bombers were accompanied by fighters. Later on, this practice was dropped as unjustified under prevailing conditions. German bombers were reported to fly from Eastern Prussia to Germany, dropping their bomb load on the way.



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GROUND DEFENCES.

Observations made tend to prove that the range of the 40 mm. calibre automatic A.A. guns have an insufficient range for effective protection against enemy bombers, though being very unpleasant for these at lower altitudes. The Warsaw batteries, after a few days' training, succeeded in bring a number of enemy aircraft down. The number of machines lost by the Luftwaffe through A.A. fire is probably about 200, about 250 being claimed as shot down by the Polish Air Force.

POSSIBLE CONCLUSIONS AS TO AIRCRAFT DEVELOPMENT, BASED ON OBSERVATIONS OF THE POLISH CAMPAIGN.

The scarcity of the presented material and the conditions—geographic, strategic, etc.—prevailing in this campaign do not justify the authors in drawing any conclusions. The temptation to do so is, however, so great that an endeavour is made to review some of the types used.

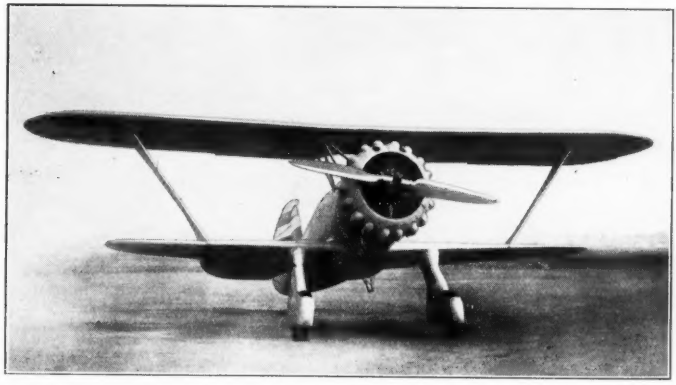
Two general points should be stressed, in the opinion of the authors, when considering the construction of the majority of service aircraft. These are, in the first instance, tactical requirements, and in the second, facility of production, as it should be borne in mind that the capacity of any industry is determined by two factors: number of man-hours available and number of man-hours required

for the production of a certain product. And it is a bitter experience gained, to know that a sufficient number of even not quite up-to-date equipment is much better than a production muddle caused by frequent changes to new types.

Aircraft Performance.

The controversy of speed versus manœuvrability will probably not cease to stir discussion for a long time to come, though a line of demarcation between the fields where each of the two performances tend to predominate is becoming apparent. The experience of the Polish campaign reaffirms that for the short range fighter manœuvrability is the more important factor than speed. The same applies to the short range and dive bombers, while for the long range and fighters of the pursuit type the opposite seems to be the general trend.

Fieseler Storch.



H.S. 123.

The maximum to minimum speed ratio for all classes of aircraft, with the exception of the long range bomber, is becoming a more and more important factor with the increase in speed and the necessity of operating from emergency landing fields. This will tend to increase the application of all sorts of high lift devices, like H.P. slots, flaps, etc. These devices may also be of use in improving the manœuvrability of some of the high-speed aircraft.

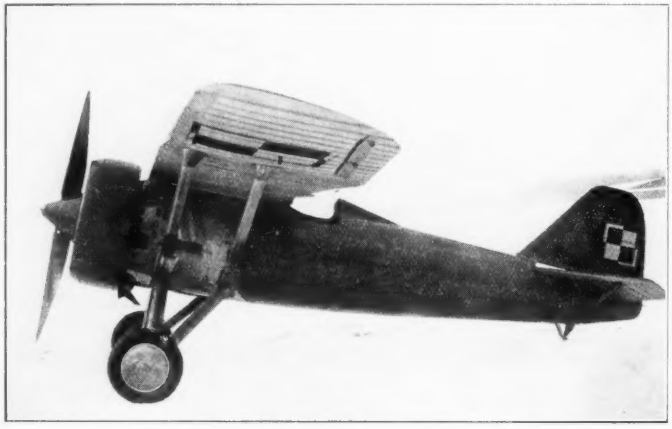
Rate of climb for interceptor type of fighters is an important characteristic, enabling it to reach operational height in a short time. All other types of service

machines do not set any special requirements in this respect. As to the ceiling, it may be assumed that this characteristic is determined for bombers by considerations of strategical requirements, and for their opponents by the type of equipment used by potential enemy. For the remaining types, this characteristic is dependent on tactical considerations.

AIRCRAFT TYPES.

Based on the negative experience of the Polish campaign, the fighter, short range bomber and army co-operation craft will be reviewed shortly.

The single-seater fighter of the interceptor type, as conceived in Great Britain a few years ago, seems to be the best protection for vital centres of national activity. It should possess a short take-off, highest possible rate of climb, great degree of manœuvrability at the operational height of the potential enemy's bombers and escort fighters. It should carry a heavy armament of machine guns or, preferably, of shell guns. The general lay-out of this type of machine is, probably, the most debatable point. The versatility of designs, some quite unorthodox, is the proof that the satisfactory solution is still to be found. The British single-engined fighters are possibly the nearest to the ideal. Many contradictory requirements are faced by the designer of this type of aircraft in per-



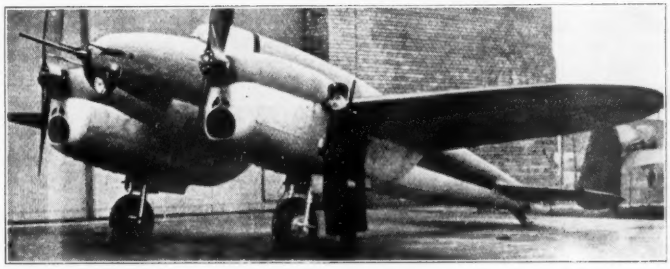
*P.Z.L. P*11.

formance characteristics, visibility, armament, protection, power plant installation and weight distribution. Cost of production, as figured out in man-hours, and reliability are points that should also be kept in mind.

In order to establish the performance characteristics, more experience is to be accumulated from actual aerial engagements, so that a good balance could be established between manœuvrability and speed. It seems, however, that comparatively low wing loadings, coupled with low power loading and the addition of some form of high lift devices for increasing the lift coefficient, are essential for such aircraft. This further requires still lighter and more powerful engines with high altitude rating and small frontal area. The liquid-cooled engine is apparently, for the time being, the winner in this class, though an air-cooled engine of suitable geometric layout would probably have received a warm welcome. There are, however, no indications that such an engine will materialise. Considerations of weight, ease of installation and accessibility to the power plant, as well as a great deal of experience accumulated, tend to be in favour of the

installation of the engine in the nose of the aircraft. The resulting disadvantage is poor visibility, and what is more important, complications in gun mountings. The trend to increased shell gun of comparatively large bore makes it necessary to use this type of gun mounting, which has the great advantage of having them in an accessible place in case of jamming and similar defects in action. As to the armament itself, a judicious consideration of the weight question of a great number of quick-firing rifle-bore machine guns, versus larger shell-bore guns, or still larger shell gun, is necessary in order to find the best solution, the aim being to have the greatest concentration of fire possible during the comparatively short moments of action.

P.Z.L. 37.

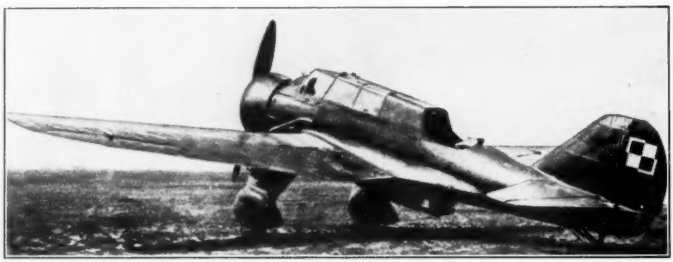


P.Z.L. Wilk.

Another type of fighter whose usefulness in co-operation with the interceptor type is apparent is the pursuit fighter, whose part is to engage enemy bombers at a distance beyond the range of the interceptor. It will have to face the escorting fighters and should be able to cope with these. As it will have to combat ships of high speed and comparatively low manœuvrability, particularly if the bombers have not had the chance of unloading their bombs before, speed will have to be the primary characteristic of such fighters. They will probably have to be equipped with heavy armament of the shell gun type of large bore and long range, firing explosive shells. It may be noted in this instance, that it is considered improbable that running fights on parallel courses will be ever encountered in actual engagements, and it is thought that the great care sometimes exercised to widen the field of fire to the sides of the craft, is not quite justified. An elliptical cone with its long axis in the vertical plane of symmetry is probably all that is wanted. It would be interesting to hear the comments of those with actual

experience in this subject. For protective armament the pursuit fighter will be probably equipped with machine guns with a wide field of fire in the vertical plane. Requirements of range, load and speed apparently confine this class of craft to the multi-engined type. The basic plane for this type can be of the same lay-out as that for short and medium range bomber, which will favour ease of production for some of the component parts, at least. Some form of armour for the pilot and the rear gunner, who is probably having the hardest time of the whole crew, is necessary. It may be remarked, in this instance, that the addition of armour to existing aircraft is a very unpaying proposition with resulting waste of material and increase of weight. It will be possible to make it in a more economic way in new designs, where the armour elements will be made to transmit stress, as a constructional element.

*P*11.



P.Z.L. LXXIII.

The short and medium range bomber is now a twin-engined aircraft of about 15,000 to 20,000 lbs. gross weight. It is essentially a carrier of bomb load, and may be regarded as an extension of long range artillery. It should possess in the highest degree the ability of surprise action, which means that it should possess high cruising speed and high ceiling. In case of encounter with enemy fighters, and on release of its bomb load it should possibly not be outdone by these as to manœuvrability. Its firing power cannot, however, equal that of the fighter and some protection in the way of armour around the vital parts is therefore necessary. This will add more weight and will tend to increase the size of the aircraft.

There is one class of bomber that was found very effective in the Polish campaign and that is the dive bomber. This type is worth deserving close study and development. The British Gloster Gladiator will probably prove to be a worthy adversary for the German Ju 87 and Hs 123.

The army co-operation and observation aircraft are tending to become more specialised for the different duties they are expected to perform, that it is difficult to enter more closely into their study in a lecture like this, and the more so, as the authors do not feel justified to comment on this type of aircraft because of the insufficient experience.

We have had in Poland some experience with air-cooled engines and this was a highly satisfactory one, so it may be that our views are somewhat prejudiced in their favour, though if statistics may prove something, they also are apparently in favour of the air-cooling. More and more power will be required from the engines with simultaneous decrease of weight per h.p. It seems, however, that simplification of design in the direction of simplifying production difficulties, is still more important in wartime industry.

Discussion.

Mr. E. C. Gordon England (*Fellow*): His first reaction, on hearing the paper presented, was to feel extremely humble; he congratulated the authors most heartily on having dealt with a very difficult subject so adequately in a language other than their own. He added that it was very remarkable that at such a time and in such circumstances as those obtaining during the war the Royal Aeronautical Society should have been able to arrange for the presentation of a paper on such an important matter.

Asking the authors to comment further on their statement that " . . . it is impossible to visualise any country, even one with a highly developed industry, being able to find employment in peace time for the number of men and women indispensable during war time expansion of industry," Mr. Gordon England said that he, personally, held the directly opposite view. He believed there was no difficulty, in an industrialised country, in finding the necessary people and having them available in peace time to meet the conditions that would obtain in war time. He asked whether the statement he had quoted referred particularly to a country which was not highly industrialised.

Mr. Dziewonski: In the first instance the statement was intended to refer to Poland, which was certainly not a very highly industrialised country. But he still considered that even in a very highly industrialised country it was not possible to employ in peace time all those men and women who were indispensable in war time, because in war time industry had to expand very greatly. In that connection he referred to some very interesting calculations published in a recent issue of " The Aeroplane," in which some very large figures were arrived at as indicating the number of workpeople necessary for serving an active Air Force of 25,000 or 26,000 aeroplanes.

Mr. Gordon England: He urged that the matter was one requiring more detailed consideration, and he drew attention to the very rapid industrial expansion which was being effected in America, a highly industrialised country which was not at war. He believed that in this country, also, they would find no shortage of the people capable of helping such an expansion, and, he added, that in his own experience he had found no difficulty whatsoever. It was rather a technical matter, concerning the use that was made of the services of the people available; and he asked for the authors' criticism of his suggestion that they needed to design all aircraft, engines and accessories in such a manner that their manufacture did not call for specialised training, that the process of manufacture could be so split up that practically anybody of normal intelligence could be drafted into the various works, within a few days, to make an effective production unit.

Mr. DZIEWONSKI: He entirely agreed that more stress should be laid, when designing aircraft and engines, on ease of manufacturing even at the cost of some sacrifice in performance which it is believed is not necessarily entailed. The opposite is probably true in many instances. Standardisation of components and sub-assemblies, as well as restriction of diversity of types in all classes of service aircraft, are very important from the production point of view. This applies, of course, to engines and the vast field of accessory equipment as well. Striving for highest performance at the risk of slowing down production would be a dangerous procedure in wartime.

Mr. GORDON ENGLAND: The training schemes of the Lockheed Company, in America, were well worthy of study as applying to that particular problem.

With regard to the protection of the workpeople during air raids, he said he had gathered from the paper that the authors did not favour the provision of outside shelters.

Mr. DZIEWONSKI: Outside shelters could be considered sufficiently effective for protecting factory workers, provided they were at a reasonable distance from the works and easily accessible for the personnel. This point should be emphasised, if casualties caused by hasty evacuations are to be avoided. Provision should also be made for an independent source of supply of light near all exits and near the shelter entrances. There is no doubt, however, that the time lost during evacuation, in case of frequent raids, is a factor that will bear heavily on the works output. Really bomb-proof factories present a very marked advantage from this point of view.

Mr. GORDON ENGLAND: Did they prefer that shelters be provided inside the actual factories?

Mr. DZIEWONSKI: He favoured the building of a factory in such a manner that the more important departments were underground and well protected from bombs, so that they could continue working during air raids; otherwise there would still be great disorganisation owing to the workpeople leaving their departments during air raids, even though no bombs were dropped.

Mr. GORDON ENGLAND: He gathered that the authors strongly advocated the provision of bomb-proof factories.

Mr. DZIEWONSKI: He agreed, although he appreciated that the provision of such factories might be very costly.

Mr. GORDON ENGLAND: Discussing the section of the paper which gave three possible forms of organisation of industrial plants of military importance, he said that possibly the authors had in mind that the first possible form of organisation (the sub-division of large plants into a number of smaller units, those subsidiary units possibly being duplicated) would fail as completely as any other unless the whole of the plants were duplicated.

Mr. DZIEWONSKI: He agreed.

Mr. GORDON ENGLAND: He criticised as illogical the third possible scheme (entailing the removal of whole factories to places outside the range of enemy bombers), because if the factories were so far away that enemy bombers could not reach them, then the products of those factories could not be brought to the fighting line effectively and quickly, for the transport problem would probably be too difficult—unless it were assumed that the enemy had short-range machines and the other side had long-range machines.

Mr. DZIEWONSKI: The latter assumption would not be a fair one, of course. But equipment could be transported over long distances to the fighting line, just as it was being transported from America at the moment. The American plants were supplying machines for use in the war, and those plants were at the moment bombproof, in the sense that they were situated at a great distance from hostilities.

Mr. GORDON ENGLAND: He urged that the problem of transport would be difficult, and that that was a weakness in the third possible scheme suggested in the paper.

Mr. DZIEWONSKI: He agreed that transport difficulties would have to be accounted for, but he still thought that this scheme presented considerable advantages, which fully justified a most thorough study of the problem at the present time.

Mr. GORDON ENGLAND: With reference to the list of German aircraft taking part in the Polish campaign, as given in the paper, he asked for further information as to the purposes for which the Fieseler Storch was used, whether for battery spotting or other specific purposes, because it was comparatively old. He believed it had been used very largely in the campaign.

Mr. DZIEWONSKI: He believed it was used only for purposes such as battery spotting and for general observation for the High Command.

Mr. GORDON ENGLAND: Had it been used for communication purposes behind the German lines, for carrying officers, etc.?

Mr. DZIEWONSKI: He did not know.

Mr. GORDON ENGLAND: He had been very much impressed by the application of the air-cooled engine to the high-speed fighter by the American aircraft industry; some very remarkable speeds had been achieved by aircraft to which that engine was fitted, and it was claimed that the Vultee-Vanguard, fitted with the 1,500 h.p. Pratt and Whitney long-shaft engine, was achieving a speed of more than 400 m.p.h. He asked whether the authors of the paper had considered the possibilities of the air-cooled engine as used in that way, or used possibly as the Bell Air Cobra was using the liquid-cooled engine. When used in that way, was there any difference between the frontal area of the liquid-cooled and air-cooled engines?

Mr. DZIEWONSKI: Recent developments in cowling and cooling of radial engines tend to decrease the gap between air and liquid-cooled engines, as to performance obtainable on high-speed aircraft, but there was probably still something to be said in favour of the liquid-cooled engine as to frontal area, weight and wetted surface of its cowling. Besides, the H and particularly the V type engine in single-engined aircraft have the further advantage of enabling guns to be installed in the fuselage, firing along the cylinder banks or through the hollow reduction gear shaft, which cannot be easily achieved with a radial engine, particularly of the multi-bank staggered cylinders arrangement. Viewed from this angle the controversy is not so much between air versus liquid-cooling, but regarding geometry of lay-out—whether the cylinders should be built around one or two cranks, or around six.

The power plant installation of the Air Cobra is very attractive, but has the drawback of added weight and impaired accessibility to the power plant, to say nothing of the increased cost of production, as figured out in man-hours, which probably brings the balance down against this lay-out for service equipment.

Mr. GORDON ENGLAND: He expressed great interest in the problem of the number of guns carried by fighter aircraft, and suggested that some discussion with regard to it would be helpful. The dive bomber, to which interesting reference was made in the paper, seemed to be a most effective military weapon, judging from the fighting that had taken place so far, and he wondered whether they in this country were paying sufficient attention to it.

Finally, he expressed gratitude to the authors for having prepared their paper, and said the British aircraft industry was very fortunate in having secured their services.

Mr. D. L. ELLIS (*Associate Fellow*): One of the outstanding points raised in the paper was the manner in which one or two lucky hits by bombs—from the attacker's point of view—could put a factory out of action. It might be rather late in the day to think about such things, but that was no excuse for forgetting them altogether. He imagined there were very few factories in this country which could not be put out of action completely by even one lucky hit; a power house was the sort of unit that came to mind. He added that, the more a factory was organised for line production, the more vulnerable it became. It

might be possible to re-organise even modern factories so that, instead of having single-line production, they might have two or three lines in parallel, in order to prevent an entire factory organisation being stopped as the result of a lucky hit by a single bomb. He also pointed out that a great many small hand tools were used, both electric and pneumatic, and usually in a factory they were supplied by one single central compressor or motor; a 20-lb. bomb could probably settle that, and might have the effect of stopping the operation of a whole erecting and fitting shop. The placing of factories out of range of raiding aircraft was rather a counsel of perfection. Apparently the authors of the paper did not approve of the use of multiple machine guns and light shell guns as protection against low-flying aircraft; he asked if they could express their views on any alternative method of defence, particularly against dive bombing, which appeared to be the most effective bombing attack.

Mr. DZIEWONSKI: The reply to Mr. Ellis's question has already been given to Mr. Gordon England, but it may be added that for ultimate protection of plants of the highest importance from enemy aircraft, a large number of A.A. guns of a diversity of calibre and range, in order to be able to cope with aircraft flying at different heights, is necessary, with the lighter quick-firing automatic guns of the Bofors type and heavy machine guns located close to the works, for dealing with dive bombers and low-flying aircraft.

Mr. B. S. SHENSTONE (*Associate Fellow*): He disagreed with Mr. Gordon England's criticism of the proposition to remove whole factories to places outside the range of enemy bombers. After all, the products of the factories, for delivery to the fighting forces, had to travel only one way, whereas enemy bombers had to travel both ways. The proposition was not necessarily too idealistic; machines were coming to Great Britain from Canada, which was only 2,000 miles away, and published figures showed that the Wellington bomber could fly 3,000 miles. So that he felt that the final solution would be the development of the Canadian factories.

The authors' references to speed versus manœuvrability were worth remembering. The tendency for wing loadings to rise so much with speed, of course, affected manœuvrability very markedly. They might find that in some cases Gladiators would represent one of their most effective protections.

Particular interest attached also to the authors' references to the long-range fighter, which must co-operate with bombers or attack enemy bombers, and he invited the authors to discuss further the sort of performance and range that such machines should have.

Mr. DZIEWONSKI: The range of machines depended very much on the strategic situations of the countries involved in war.

Mr. SHENSTONE: He asked whether the authors considered that the range of a long-range fighter should be, say, twice the distance from the attacked country to the bases of the enemy country, so that they could travel from the border to the middle of the enemy country, and back again.

Mr. DZIEWONSKI: That probably is so, and perhaps the range should be even longer. But one must consider the matter on the basis of strategic considerations.

Mr. SHENSTONE: Was armour used on the Polish machines or found on any of the German aeroplanes?

Mr. DZIEWONSKI: Armour was not used on the Polish machines, apart from the armoured chairs provided for the pilots. The thickness of armour used on those seats was 6 mm. There was no armouring in the German planes that were brought down in Poland.

Monsieur WOUTERS (Belgian Military Air Attaché): Would the authors deal further with the use of machine guns or cannon on fighter aircraft, and say whether they had any definite reasons to prefer the shell gun or cannon?

Mr. ROGALSKI: He had in mind a special type of fighter carrying a gun of about 40 millimetre or even larger bore, equipped with a combined optical sight and range-finder. This fighter would fire time-shells from a predetermined dis-

tance for which the range-finding sight would be set. This installation, a flying A.A. gun, would have the advantage over its ground counterpart of mobility and ability to fire in the line of flight of the target, from a distance which will make it immune from enemy bomber armament. Aiming and range-finding would not present any difficulty, with the aid of the proposed optical sight range-finder.

The CHAIRMAN: Commenting on the authors' reference in the paper to the manufacture of certain types of poppet valve engines, he asked what was the Polish Government's policy with regard to the sleeve valve engine of the Bristol type. He believed the latter was the subject of a licensing arrangement between the Bristol Company and the Polish aviation authorities, and he would like to know whether those engines were manufactured in Poland and whether they were used during the Polish campaign.

Mr. DZIEWONSKI: Licensing arrangements had been made between the Polish Government and the Bristol Aeroplane Company for the manufacture of sleeve-valve engines. Only the jigs and tools were in preparation for the production of the engines in Poland; the actual manufacturing of engine parts had not, however, been started, and no experience was gained as to the use of these engines in war.

The CHAIRMAN: Had it been the future policy of the Polish Air Force, so far as air-cooled engines were concerned, to use the single sleeve valve type of engine?

Mr. DZIEWONSKI: Yes, to a great extent.

The CHAIRMAN: It was very satisfactory to note the statement in the paper that, among the engines of British design used, no cases of breakdown were reported during the period of the war. With regard to the arming of aircraft, he asked whether guns of the 20 mm. type, of which the German Air Force had a considerable number, were used in the Polish campaign, either against other aircraft or against ground targets.

Mr. DZIEWONSKI: The Messerschmidt machine which was equipped with the shell gun had not been used to a very great extent in Poland; but it had been used against ground targets, such as trains and armoured cars, and had proved very effective. The number of Polish fighters shot down during actual fighting in the air was not very great; the greatest number of Polish aircraft was destroyed when on the ground. Owing to the difficulties with fuel and oil, servicing and supplying, when Air Force units had to be moved from day to day to new landing fields, the ground organisation was not able to cope with the conditions and this finally put the remainder of the Polish Air Force out of action. So that the campaign did not provide any actual information concerning the effectiveness of the shell gun, as opposed to the machine gun.

The CHAIRMAN: Referring to the design characteristics of certain machines, suggested at the end of the paper, which machines should carry shell guns and ordinary 0.303 guns, he asked whether the authors visualised that such machines should be fitted with, say, two or more 0.303 guns firing forward through the airscrew and two or more 20 mm. cannon in the wings. If so, what were their ideas with regard to the amount of machine gun and cannon ammunition which such fighter aircraft should carry?

Mr. DZIEWONSKI: That depended very much on the conditions in which the fighters would have to operate. Probably a fighter of the interceptor type would not need to carry a very large amount of ammunition, for such a machine must be light.

The CHAIRMAN: He dwelt briefly, for the benefit of the many distinguished Polish gentlemen present at the meeting, upon the history of the Royal Aeronautical Society, the oldest scientific society dealing with aeronautics in the world. It was in its 75th year. It was interesting to recall that one of those who had set to work and had actally founded the Society, in collaboration with a small band of others, was that great pioneer, Sir George Cayley, rightly called the Father of British Aeronautics. Sir George Cayley was born at Brompton,

Yorkshire, before the year 1780, and died at about the time the Royal Aeronautical Society was founded. In 1852 he had been elected to Parliament for the Borough of Scarborough; indeed, it had been suggested that he had entered Parliament merely in order to draw public attention to aerial navigation, a subject which, rightly and with remarkable foresight, he had realised to be of the greatest importance to mankind. As early as 1809, *i.e.*, a few years before the Battle of Waterloo, he had expressed complete confidence in the practicability and security of aerial navigation; and the imaginative breadth of his conception of air travel could not be more forcibly expressed than in his own words:—"The air is an uninterrupted navigable ocean that comes to the threshold of every man's door, and ought not to be neglected as a source of human gratification and advantage." They would appreciate how far removed aeronautics had become from the idealist conception of Sir George Cayley, and others of his time, when they considered the terrible way in which the German nation had used that great invention against the very gallant Polish nation, two of whose very distinguished aeronautical engineers had presented so interesting an address to the Society. Knowing that millions of the Polish people were on the borderline of starvation, one wondered how they were able to carry on and resurrect their country, as they were setting out so bravely to do. In that connection the Chairman recalled a recent broadcast talk given by or under the authority of Captain Grudzinski, who commanded the famous submarine "Orzel," which had escaped from Reval, or Tallinn, at the northern end of the Baltic, and, after nearly 50 days at sea, had arrived in the Firth of Forth. Whilst in the Kattegat, or thereabouts, when the vessel was lying on the bottom of the sea and was being attacked with depth charges by German surface vessels, a conversation had occurred between Captain Grudzinski and a German official who was on board, and who was landed subsequently on the Swedish coast. The German official was becoming rather alarmed about being bombed by his own countrymen; and, after asking whether he was likely to get out of the vessel alive, he had added, "Of course, all we Germans look to our leader, the Führer, as the man who will bring us to victory and save us from all evils." Captain Grudzinski had replied that that was interesting, because all Polish people relied upon God to help them in the hour of need and distress, and upon the blessed Virgin, our Lady of Czestochowa.

That, said the Chairman, was a remarkable illustration of the tremendous spiritual conception of the Polish people in meeting the fearful scourge that had fallen upon them; and the Royal Aeronautical Society was proud indeed to welcome the two distinguished Polish gentlemen who had presented the paper, together with their fellow countrymen who were present. He assured the authors that their paper would be widely read, not only by those in charge of the Royal Air Force and the Fleet Air Arm, but also by those concerned with all phases of British enterprise. Therefore, he proposed a very cordial vote of thanks to them, on behalf of the Society and its guests.

A RATIONAL DEFINITION OF YIELD STRENGTH.*

By W. R. Osgood,† Washington, D.C.

Explicitly or implicitly the yield strength of a material is often used as a measure of incipient structural damage. With the yield strength determined by conventional methods, however, it cannot be said in general for two structural elements geometrically alike but of different materials that similar loads, producing maximum stresses equal to the yield strengths in the two cases, are simply related to the yield strengths. A definition of yield strength is proposed in this paper which often has the advantage that, for geometrically similar structures of different materials, loads producing maximum stresses equal to the yield strength are proportional to the yield strength.

It is generally recognised that most definitions of yield strength are arbitrary. Except in the case of the simplest stress-strain diagram composed of two straight lines, the modulus line and a horizontal (approximated in mild steel), the commonly used definitions of yield strength or yield point have limited physical significance. This difficulty is likely to inhere in any definition of yield strength, but there is an objection to most definitions which can be avoided or mitigated in many cases. When the yield strength is used as a measure of maximum allowable deformation of a structural element, no simple relation exists in general between the damaging deformations obtained with two materials having different stress-strain curves, except under conditions of pure tension or compression. Where it is a question of failure by instability in the plastic range, no simple relation exists in general between the critical loads obtained with two such materials. By defining suitably the yield strength, however, simple relations may be found between the damaging deformations or between the critical loads. These statements become clear as to deformation when, for example, bending is considered.

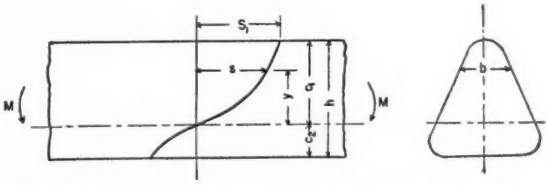


FIG. 1 STRAIGHT BEAM SUBJECTED TO BENDING MOMENT M

Suppose that a section of a straight beam is subjected to a bending moment M such that, in the extreme tensile fibre, a yield strength S_1 is just reached. Then from Fig. 1 we may write

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* Reprinted by courteous permission of the American Society of Mechanical Engineers from their Transactions of June, 1940.

† National Bureau of Standards.

$$M=\int_{-e_2}^{e_1} sybdy$$

Since $y=he/(e_1-e_2)$, this equation may be written

$$M=\frac{h^2}{(e_1-e_2)^2}\int_{e_2}^{e_1} bsede$$

where e is the strain in the fibre at the distance y from the neutral axis, and e_1 and e_2 are the strains in the extreme tensile and compressive fibres, respectively. Now consider a second beam of the same cross-sectional dimensions but of different material subjected to a moment M' which produces a tensile extreme fibre stress equal to the yield strength S_1' of this material. The relation between bending moment and extreme fibre strains e_1' and e_2' for this beam is

$$M'=\frac{h^2}{(e_1'-e_2')^2}\int_{e_2'}^{e_1'} bs'e'de'$$

The two moments M and M' will be simply related only if a simple relation exists between the stress-strain curves of the materials. If the two stress-strain curves are affinely related, that is, the one curve could be got from the other by the transformation

$$e'=\alpha e \quad s'=\beta s \qquad . \quad . \quad . \quad . \quad . \quad (1)$$

where α and β are constants, then we should have for the second beam

$$M'=\frac{h^2}{\alpha^2\,(e_1-e_2)^2}\int_{e_2}^{e_1} b\beta s\alpha^2 ede$$

$$=\frac{\beta h^2}{(e_1-e_2)^2}\int_{e_2}^{e_1} bsede$$

or

$$M'=\beta M \qquad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

the simplest possible relation between the two bending moments. It is seen from equation (1) that with S_1 the yield strength of the first material and S_1' the yield strength of the second, it is possible to define yield strength in such a way that $\beta=S_1'/S_1$. It will be explained later how yield strength must be defined in order that β will have this value.

The determination of α and β is illustrated by Fig. 2, which shows two stress-strain curves, related by equation (1). We have for any corresponding points

$$s'/e'=\beta/\alpha\times s/e \qquad . \quad . \quad . \quad . \quad . \quad (3)$$

This equation states that β/α is in the ratio of the secant moduli for corresponding points, which in itself is not of much help. At the origin, however, this ratio is E'/E, the ratio of the moduli of elasticity, a known quantity. Since equation (3) is an identity, in that it holds for all corresponding points, we see now how to identify such points. The secant moduli for corresponding points on the stress-strain curves must be in the ratio of the moduli of elasticity. Corresponding points, therefore, are the points of intersection with the stress-strain curves of lines through the origin (secant-modulus lines) having slopes proportional to the moduli of elasticity, such as the lines in Fig. 2 with the slopes

mE and mE', where $0 < m < 1$. The values α and β are now seen immediately to be given by

$$\alpha = \frac{e_1'}{e_1} = \frac{S_1'/(mE_1')}{S_1/(mE)} = \frac{S_1'E}{S_1E'} \qquad \beta = \frac{S_1'}{S_1} \quad . \quad . \quad . \quad (4)$$

where the points (e_1, S_1) and (e_1', S_1') are the points of intersection mentioned. The values α and β do not depend upon m because any value of m between 0 and 1 determines corresponding points, and by the hypothesis of equation (1) α and β are constants. If the stress-strain curves are single straight lines, α and β may have any values subject to the condition $\beta/\alpha = E'/E$.

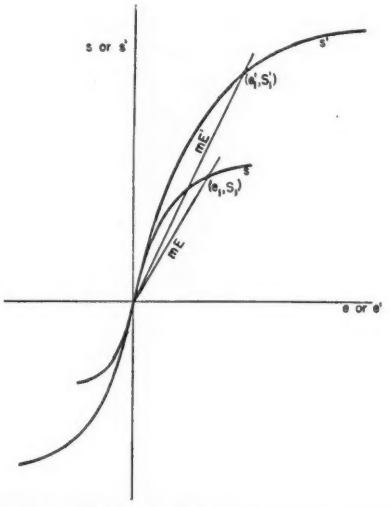


FIG. 2 STRESS-STRAIN CURVES TO ILLUSTRATE THE DETERMINATION OF α AND β

It now becomes evident how yield strengths must be determined if equation (2) is to hold. By referring to equation (4) for β, it is clear that the yield strength must be defined as the stress represented by the intersection with the stress-strain curve of a line through the origin, having a slope m times the modulus of elasticity of the material, where $0 < m < 1$.

Examination of a considerable number of (compressive) stress-strain curves of different materials has shown that, for a given material (as supplied commercially, for example), the relations in equation (1) do often in fact actually hold to a good degree of approximation. In order to determine whether two stress-strain curves are affinely related, as indicated in equation (1), it is only necessary to draw several secants with slopes m_1E, m_2E, . . . m_nE for the one curve and with slopes m_1E', m_2E', . . . m_nE' for the other curve. If the two curves are affinely related, it will be found that the ratios of corresponding strains e_1'/e_1, e_2'/e_2, . . . e_n'/e_n are all equal, equal to α, let us say; and that ratios of corresponding stresses s_1'/s_1, s_2'/s_2, . . . s_n'/s_n are all equal, let us say equal to β.

The choice of m for determining yield strength is largely a practical matter. If m is taken less than $\frac{1}{2}$, the stress-strain curve of the material will have to be obtained for greater strains than is now customary. On the other hand, if m is taken near to 1, the yield strength so determined will be a stress below which little plastic action has occurred.

This method of determining yield strength (in compression) has been used by the author for some years to compensate for variations in test results* due to variations in the mechanical properties of the materials of the test specimens. It was being used by the Heintz Manufacturing Company, Philadelphia, Pa., in 1936, according to information received by the author at the time from F. M. Lambert of that company.

* "Column Curves and Stress-Strain Diagrams," by W. R. Osgood, National Bureau of Standards, *Journal of Research*, Vol. 9, Research Paper No. 492, October, 1932, pp. 571-582.

"Column Strength of Tubes Elastically Restrained Against Rotation at the Ends," by W. R. Osgood, National Advisory Committee for Aeronautics, Report No. 615, Washington, D.C., 1938.

"The Crinkling Strength and the Bending Strength of Round Aircraft Tubing," by W. R. Osgood, National Advisory Committee for Aeronautics, Report No. 632, Washington, D.C., 1938.

"The Column Strength of Two Extruded Aluminium-Alloy H-Sections," by W. R. Osgood and Marshall Holt, National Advisory Committee for Aeronautics, Report No. 656, Washington, D.C., 1939.

FIRE PROTECTION OF PETROL TANKS.

By A. R. Weyl, *Associate Fellow.*

Introduction.

Petrol is a highly inflammable fluid which can be ignited easily and whose vapour forms with air a highly explosive mixture.

There are, however, possibilities of giving a certain amount of protection against such fire risks created by damage to petrol tanks.

The three main problems which have to be dealt with are:—

(i) To exclude an ignition which may be caused by bullets hitting a petrol tank;

(ii) To seal leaks caused by bullet holes;

(iii) To prevent fire after a crash.

These problems are by no means new. A large amount of research and experimental work has been devoted to their solution.

History.

Even before the war of 1914-18, the protection of petrol carried by aeroplanes was being considered. Louis Blèriot, who had had some unpleasant experiences with petrol fires, showed at the Paris Saloon of 1908 a Blèriot high wing monoplane, type IX, the petrol tank of which was placed nearly 2 ft. below the bottom of the fuselage. This is a tank location which later was found to give a good protection in the case of fire occurring during a flight.

While most aeroplane designers of the pre-war period utterly disregarded the danger of petrol tank fires, we find late in 1911, in a somewhat inconvenient sesquiplane of Coanda, petrol tanks arranged in a cantilever parasol wing, remote from the two engines which were in the nose of the fuselage. This aeroplane was designed for the French " Concours Militaire " and did not prove successful. But the idea of placing gravity petrol tanks in the upper wing remote from the engine is still to-day considered as giving a fair amount of safety and reliability.

In 1913-14, the Swiss designer F. Schneider secured pioneer patents for the jettisoning of petrol from tanks (German patent No. 611,018, June, 1914), for petrol tanks which could be jettisoned (German patent No. 286,735, May, 1914) and for a tank equipped with a container holding fire extinguishing chemicals which would be released in a crash, thus preventing the petrol from catching fire. Incidentally, Schneider's aeroplanes were among the first military types to use a petrol pump for feeding the petrol from the main tank into a small gravity tank and from there to the carburettor (1913), while most other types at that period employed pressure tanks.

But the real interest in petrol tank protection did not take place until the war had been in progress some time.

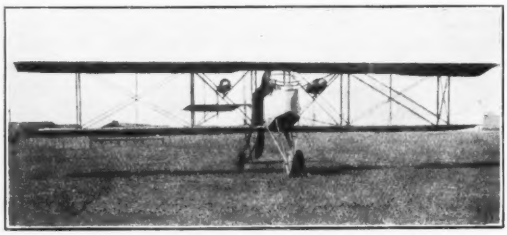
Early in the great war, frequent casualties were experienced in which aeroplanes were shot down in flames. As, at this time, parachutes were not being used men lost their lives in distressing circumstances.

With the progress in air combat and by the general introduction of incendiary ammunition,[1] the fire danger in the air grew. Of 161 Allied aeroplanes shot down during March, 1917, no less than 151 aeroplanes are officially reported to have crashed in flames.

[1] Which, originally, was intended solely for the use against balloon and airships.

Apart from the fire danger caused by immediate enemy action, the protection of the crew against petrol fires following crashes with disabled aeroplanes needed attention.

From the outset, the main danger was suspected in the petrol tanks. All available records seemed to indicate that incendiary bullets hitting engine parts, ammunition boxes or oil tanks were seldom accompanied by as serious con-



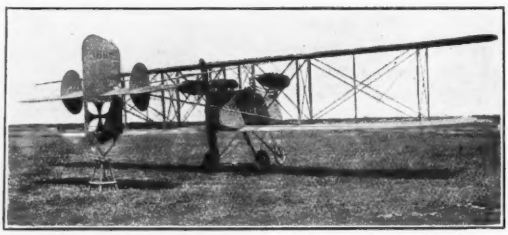


FIG. 1*a* AND 1*b*.

Bréguet-Michelin pusher of 1915. *The two petrol tanks are placed between the wings. This type won the first prize in the French Bomber Competition of* 1915.

FIG. 1*c*.

Bréguet-Michelin pusher. The mounting of the petrol tank.

sequences as hits into petrol tanks. At that time, the dangers inherent in the oxygen equipment were not so well understood.

With most of the fuel systems incorporated in Allied and German aeroplanes, the danger of petrol tank fires was aggravated by the use of pressure tanks, the air pressure in which served for the feeding of the petrol to the carburettor or into an auxiliary gravity tank. A bullet into such a pressure tank necessarily caused the petrol to splash about violently and might even be accompanied by a gas explosion within the tank. In case of a crash, pressure tanks also proved dangerous.

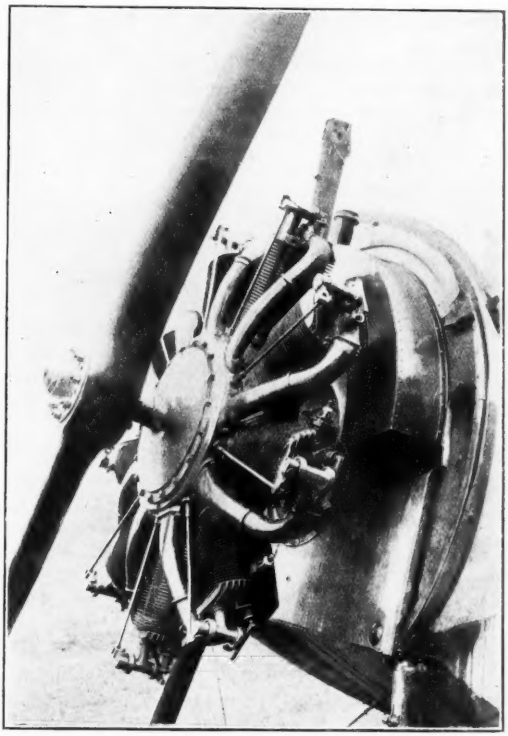


FIG. 2.

Tank position immediately behind the cylinders of a rotary engine (Nieuport 17 single-seater fighter). Defects of the engine or tank hits with non-incendiary ammunition were apt to cause fire.

The adoption of petrol pumps which took place at both sides of the lines made pressure tanks obsolete.

Another point which required attention concerned the location of the petrol tank. Auxiliary tanks were generally gravity tanks which therefore had to be placed at a sufficiently high level above the carburettor and not too distant from it. In case of an unlucky hit, these tanks were apt to sprinkle their burning content over the crew. Hence it was thought necessary to discard such auxiliary gravity tanks. But in view of the fact that petrol pumps were not absolutely trustworthy elements, the flying personnel insisted that these tanks should be

retained. It was argued that their petrol content was so small that a fire would not cause a serious harm. The fact that small tanks are more easily ignited by an incendiary bullet than a large one, was overlooked. Finally, it was ruled that all fuel systems incorporating independent auxiliary tanks (not alone the gravity tanks) should be discarded, and that a special partition within the main petrol tank should take the place of these auxiliary tanks.

With the main petrol tanks, it was recognised that a tank location which would cause the flames to be carried away by the air, without endangering the crew or vital parts of the aeroplane (tail group) would be a solution of the problem.

One of the first to consider the problem in this manner was L. Brèguet in his Bréguet-Michelin pusher bomber of 1915 (Fig. 1) where the tanks were placed between the wings.

Tanks located in or on top of the wings or behind the crew (Sopwith) were not necessarily due to a consideration of the fire danger, but they proved definitely a better arrangement than those placed immediately behind the engine (Nieuport for instance, Fig. 2), or the " easy chair " tank type, with which most German two-seaters used to be equipped.

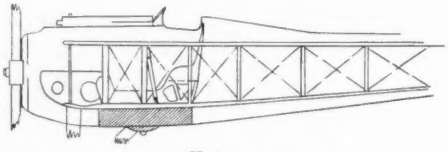


FIG. 3.

Petrol tank arrangement with Spad VII single-seater fighter. The tank can be jettisoned in flight. Content, 22 gal. Unit tank weight, 1.5 lb./gal.

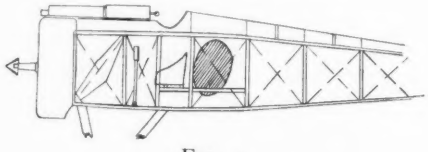


FIG. 4.

Petrol tank arrangement with Sopwith Camel. Content, 30 gal. Unit tank weight, 0.70 lb./gal.

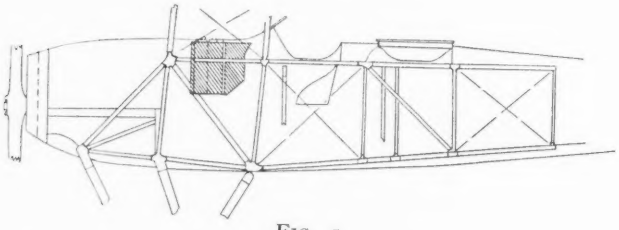


FIG. 5.

Tank arrangement with Bréguet 14 B.2 two-seater. Gravity tank divided by a cross-wise placed bulkhead into two compartments of 29 gal. each. The compartments are inter-connected by non-return valves and are each about 8 in. deep. The target area in the fore-and-aft direction is small. Few fires reported after combat. Unit weight, 1.0 lb./gal.

Later we find tanks located directly underneath the lower longerons of the fuselage, a solution apparently first employed in Spad VII single-seaters (Fig. 3) or underneath the fuselage as outboard tanks (Dornier D.I. biplane fighter, Fig. 10, Siemens SSW.D.VI parasol fighter, Fig. 9, and German Gotha torpedo seaplanes), or even located in the undercarriage (improved Fokker D.VII and Fokker C.I. biplanes).

The latter arrangement[2] with which the petrol tank formed a wing shaped fairing of the undercarriage axle members, was thoroughly tested in flight and found effective; in no attitude did spraying petrol touch the tail surfaces. This arrangement had to be dropped, because frequent leakages were experienced with the tank and its pipe connections. From the point of a crash fire, it was obviously no improvement.

The installation of petrol tanks in the floats of seaplanes formed the subject of a German patent (No. 300,060) of 1917.

At a later stage, outboard tanks were employed with the Junkers J.21/22 parasol fighters and in a neat solution of a wing shape tank placed beneath the fuselage, as a small lower wing (Amiot S.E.C.M. 110).

During the last war, it was further realised that in a crash following an unsuccessful air combat, a burning tank would still form a serious danger, even if it was properly located.

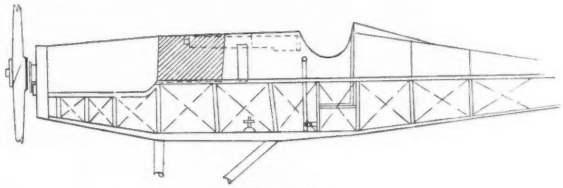


FIG. 6.

Tank arrangement of S.E.V.A. Content, 27 gal.
Unit tank weight, 1.48 lb./gal.

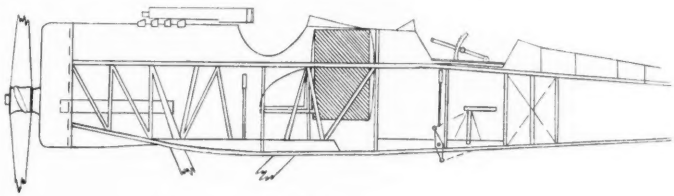


FIG. 7.

Tank arrangement of D.H. 4 two-seater. Content, 56 gal.
Unit weight of tank, 0.90 lb./gal.

The next development was, therefore, to mount the tank so that it could be instantaneously dropped in case of danger. In the war, twin-engined Caudron biplanes were apparently the first to be equipped with such tanks. Similar tanks were further provided in the latest German fighter aeroplanes of 1918.[3] To-day, tanks which can be dropped are fairly commonly employed with military aircraft. But with stressed skin constructions, structural difficulties are involved.

The idea of jettisoning the petrol was not considered favourably as in the case of a tank catching fire, the time required for draining it was thought to be excessive. It may be mentioned that even early Spad VII fighters were provided with a device for ripping part of the bottom of the tank along a soldered joint,

[2] German Patent No. 322,048 of April, 1918, and No. 365,749.
[3] See also German Patent No. 342,084 of 1918.

by means of a steel cable. It was claimed that this device would also work automatically if an explosion happened to take place within the tank. It is not known if this device proved effective with a tank fire in the air, but it should be noted that later Spad types were equipped with an improved arrangement for jettisoning. To-day, jettisoning devices are not considered suitable in a petrol tank fire.

From the outset, it was considered fairly hopeless to put out a burning tank with the help of fire extinguishing means. A fire extinguisher was only considered of use against a smaller and well located fire such as a grazed petrol pipe which had started burning or a smouldering incendiary bullet deposited in the cartridge container, for instance. Consequently, fire extinguishers were only provided for large multi-engined aeroplanes.

The simple idea of giving the petrol tank an absolute protection by armouring it, had to be discarded by reasons of the weight involved. Tests showed that even behind an armour plating of 5 mm. thickness, rifle calibre incendiary bullets were able to start a fire, at normal air combat distance. An armour of 10 mm. (appr. 0.4 in.) thickness consisting of chromium-nickel alloy steel was found necessary for giving an absolute protection against rifle calibre fire. But this would have meant a tank weight of at least 4.8 lb. per gallon (without the mounting), *i.e.*, more than twelve times the unit weight of a modern magnesium alloy tank. It was argued that such a protection could only be given to very small gravity tanks.

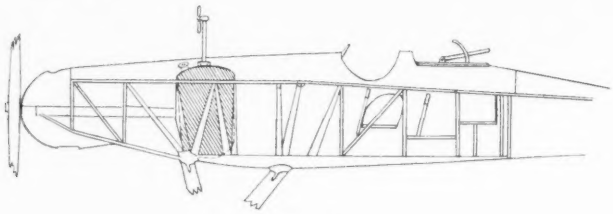


FIG. 8.

Tank arrangement of D.H. 9 two-seater. Longitudinally divided tank with loose outer cover of doped fabric leading to drain holes. Petrol feeding by means of a petrol pump.

The more serious proposal of screening the tank by placing it in a light sheet case so that petrol flowing out of a leak could be easily conducted away from the aeroplane, proved to be of doubtful value. The purpose was to catch the petrol which was streaming out of a hit tank and to conduct it away from vital parts into the open air.[1] Tests showed that the exit leaks made by bullets were such that the outer casing was also shattered, thus making the screening ineffective, as long as no armour plate was used.

At that time, it was further considered inadvisable to cause bullets to disintegrate before hitting the tank. The fragments generated by a burst of hits, it was argued, would cause such a number of holes in the tank walls, that no way of sealing could possibly be effective.

This argument, however, was controversial. Tests made often did not bear it out; hence it was not dropped till a later period in the investigations. It may be mentioned that the ammunition used is of great importance for judging this problem.

Some British types (D.H. 9, for instance) had over the petrol tank a loose cover of doped fabric which permitted leaking petrol to be conducted to drains at the bottom of the fuselage.

[1] By means of suction, see German Patent No. 375,590 of 1918.

Double-walled tanks with an interspace of approximately 4 in. width which could be used for storing such petrol which was consumed before the beginning of an air combat, were considered helpful as an intermediate solution, prior to a general introduction of protected tanks with leak-proof qualities.

During 1917 double-walled tanks were experimented with, the interspaces of which were filled with gaseous nitrogen under pressure.

The shape of a tank had been found of great importance for protection against incendiary bullets. A rifle bullet of normal muzzle velocity will not penetrate a tank wall after traversing a distance of 18 in. through fluid petrol. This fact offered good prospects for the idea of giving petrol tanks such a shape that a

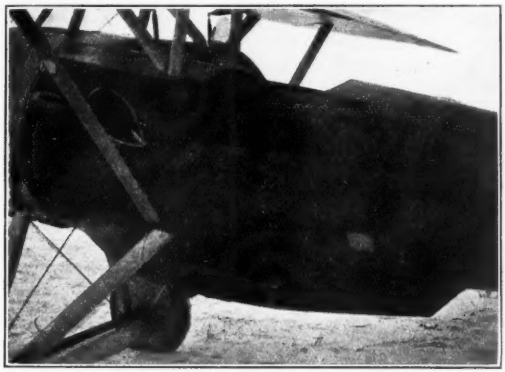


FIG. 9.

Dropable petrol tank underneath the fuselage (Siemens SSW.D.VI single-seater parasol). Safe landing with burning tank reported. Material, Duralumin. Unit weight, 0.8 lb./gal.

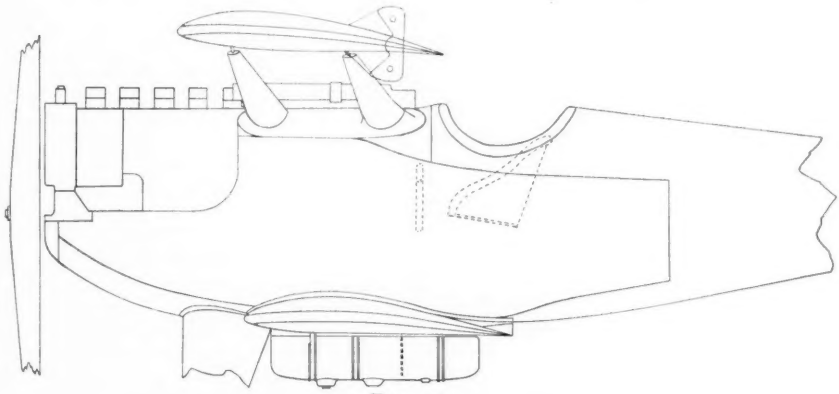


FIG. 10.

Dropable petrol tank underneath the fuselage (Dornier Do.D.I). The rear part forms the emergency tank (appr. 4.5 gal.). Content of front part appr. 13.5 gal. Material, Duralumin.

bullet would not penetrate it, but would stop inside. One is apt to think that this is really a solution, but, unfortunately, there is always a chance of a hit piercing the tank near a corner, and for this case, the protection will obviously

not exist. Experience shows, however, that quite a good proportion of bullets hitting tanks have remained in large petrol tanks.

Hence the rule was strictly enforced to mass the petrol in one tank of compact shape, to make this tank more than 20 in. long and to discontinue splitting up fuel into several tanks (some types having up to five petrol tanks for one engine, all nicely grouped with pipes and pumps around and on top of the crew). Further, all excrescences on tanks such as seat backs and arm rests of the " easy chair " petrol tanks, were condemned. Moreover, the target area of the tank in the fore and aft direction was kept as small as possible.

Practical solutions of this nature were found in the Bréguet 14 B.2 and D.H. 9 two-seaters.

The next problem to be tackled was the sealing of leaks made by bullets. It was realised that this would effectively stop a tank fire.

The sealing of leaking petrol tanks had, in France, been considered before the war. The material used was rubber. It is known that rubber swells if it becomes soaked with petrol. This is not valid for synthetic rubbers. In addition, holes made in elastic rubber have a tendency to seal themselves under the action of internal forces.

The initial experiments with petrol tanks protected by a rubber covering and treated with incendiary ammunition were disappointing. This remained the case even after it was discovered that adhesion between the rubber and metal was detrimental. Following a hit, the sheets forming the tank walls opened up, and the sealing effect of the rubber was practically negligible.

The idea of placing a rubber layer under compression inside the tank walls, acting in the same manner as a nail-proof tyre tube, offered more hope. But the idea had to be discarded because no means could be found to prevent the rubber from being destroyed by the petrol and from polluting the latter.

Synthetic rubber of the kinds which are available to-day might enable this idea to become a practical proposition. But it still remains to be seen if larger leaks will be sealed so effectively as the action against incendiary bullets requires.

The Reaction of Bullets upon Petrol Tanks.

It is commonly believed that ignition of a petrol tank can only occur as a result of an incendiary bullet. This is not so. Tracer ammunition, for instance, has been responsible for many cases of ignition, and cases of petrol tank fires after hits by ball bullets are known. It is true that the last is not easily reproduced during tests, but it seems to be beyond doubt. Its causes are not quite established; however, it is certain that the heat of the bullet is insufficient to ignite petrol.[5]

Incendiary bullets were originally devised for the attack against balloons and airships; later they became a common means in aerial combat between aeroplanes.

The most common type of incendiary bullet uses white phosphorus and is based upon the British B.T. type of 1916, which has been imitated in Germany with minor modifications. The amount of phosphorus carried in this kind of bullet is approximately 1 gram.

A peculiarity of white phosphorus is that it catches fire spontaneously on contact with air at a temperature of more than 60°C. It melts at a temperature of 44°C. with an increase in volume of 3.4 per cent.; with quickly cooled phosphorus a slightly higher melting temperature is obtained.

With a bullet, the phosphorus is ignited while being squeezed after melting out of orifices which are on the side of the bullet shell (Fig. 11). It ignites very soon after leaving the barrel and burns with a whitish smoke during its trajectory. One may assume that modern incendiary bullets are in principle similarly constructed. The disadvantages are the low cross sectional area

[5] The maximum temperature of a bullet can be up to about 160°C., which is well below the ignition temperature of petrol (about 670°C.). See also Cranz-Becker, Handbook of Ballistics, Vol. I, p. 442 (London, 1921).

loading due to the phosphorus content (the specific weight of which is only 1.82, against 11.37 of lead), giving different ballistical properties, different inner-ballistical reactions (recoil) and fairly small effective range.

Larger calibre incendiary bullets are known to incorporate thermite, a mixture of iron oxide with powdered aluminium. Thermite has to be ignited by a special composition, usually a mixture of magnesium powder with certain peroxides and either a percussion compound or a time fuse device. Such bullets differ from the incendiary ammunition already dealt with in that the ammunition generally ignites only on impact or at a time which may be set in advance. In view of petrol tank fires, the behaviour of thermite shells is, therefore, different from that of the ordinary tracer and incendiary bullets.

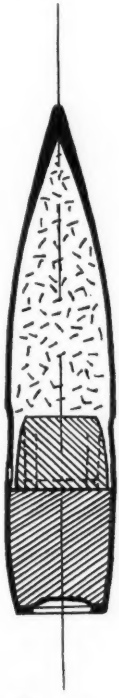


FIG. 11.

Incendiary bullet (rifle calibre). The orifices on the side are closed with an easily fusible alloy which melts while the bullet is passing through the rifling of the barrel. The molten phosphorus is squeezed out of these orifices and ignites on coming in contact with the air.

Tracer bullets (Fig. 12) usually employ a mixture of barium peroxide or strontium nitrate with magnesium powder and shellac which is ignited during the firing of the bullet. This mixture burns throughout the major part of the trajectory.

Armour piercing incendiary bullets (Fig. 13) carry a steel core in addition to a smaller amount of white phosphorus. They are of a non-tracing kind, but fire upon impact. Against tanks, this kind of ammunition behaves differently from incendiary bullets and tracer bullets.

The approximate muzzle velocity of rifle calibre ammunition is about 2,800 ft./sec.

If the problem of the protection of petrol tanks against ignition by incendiary bullets is to be tackled in an effective manner, the design requirements have to be based upon the study of the behaviour of bullets in a container filled with a fluid.

It was once held that a bullet entering a tank caused an explosion within the tank and splashed burning petrol through the burst walls of the tank.

FIG. 12.

Typical armour-piercing tracer bullet. The illuminating composition is ignited by a composition which starts to burn as soon as the bullet is fired. The orifice is at the bottom of the bullet.

This conception was found to be untrue following careful systematic research work, with the aid of slow-motion cameras, schlieren photographic devices and similar methods of modern ballistics. It was proved that the action of the bullets alone could not be held responsible for the large leaks found in tanks pierced by bullets, that the bullet did not disintegrate in the tank and so caused ignition, and that the presumed explosion was not an explosion in the chemical sense, but a purely physical event which was quite unconnected with petrol.

The following phenomena take place when a bullet is piercing a closed vessel filled with petrol:—

The entering bullet will make, provided that it enters without breaking up, a small hole in the sheet forming the wall. The edges of this hole are, as a rule, somewhat turned inwards, and its diameter is not much greater than the bullet's calibre. Oblique striking bullets, of course, cause larger entry holes.

Within the tank, the bullet moves through the fluid, thus imparting energy to the petrol. Pressure waves[6] are formed under the action of the impact of the bullet upon the fluid particles. As petrol is a very mobile fluid, it is very liable to set up such pressure waves, and only a minute proportion of the kinetic energy spent by the bullet will be converted into heat.

Pressure waves, travelling in the direction of the least resistance, *i.e.*, in the direction of the trajectory of the passing bullet, tend to burst the tank wall opposite to the entry hole immediately after the bullet has pierced the wall, while leaving the tank. It was expected that bursting of the tank wall before the exit of the bullet or without any exit of the bullet, could take place, but this has not been observed.

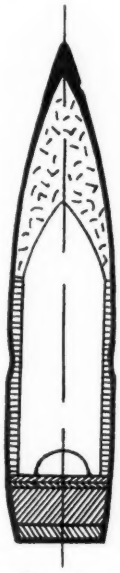


FIG. 13.

Armour-piercing incendiary bullet. The phosphorus is completely enclosed in front of the steel core and is splashed out upon impact.

After the bullet has left the tank wall making an exit hole similar to the entry, the pressure waves put a strain on the wall by impact, and an irregularly shaped large leak hole is formed, the extended and usually very rugged edges of which are bent outwards. This gives the impression of a detonation having taken place inside the tank. Plain water, however, gives exactly the same result.

The area of the exit leak is, allowing for such factors as trajectory speed, wall properties, etc., directly proportional to the free distance within the fluid through which the bullet passes before it forms the exit hole. The greater this distance, the more extended will be the leak. Ordinary rifle calibre bullets, fired by machine guns, give leaks of about 8 to 14 in. average diameter in tank walls of brass or tinned steel sheet. If several leaks are observed, the bullet either has disintegrated, or the tank has local reinforcements or an irregular shape.

[6] In outer-ballistics (see Cranz-Becker, Vol. I, para. 74) often termed "explosive waves." This expression is discarded here in order to distinguish this phenomenon clearly from an explosion caused by a chemical reaction.

It was found that the impact of the pressure waves can be lessened by the insertion of baffle plates across the trajectory of the bullet. Fairly thin gauges of light alloy sheets proved to be quite effective. The more baffle plates were inserted the smaller became the impact of the pressure waves upon the tank walls.

The baffle plates may take up the impact energy by elastic or by lasting deformation, but they may also be broken. Thus it is evident that, if several bullets hit the tank, the effect of the baffle plates may be considerably reduced. With the fire rate of modern machine guns, the probability of a burst of bullets hitting a tank is fairly high, especially in the fore-and-aft direction.

While a synchronised machine gun of the last war had a fire rate of seldom more than 600 rounds per minute, a modern rifle calibre outboard machine gun will have about twice as much, and future arms may do even more. In addition, the number of guns firing at the same time, has increased. While the target of to-day is moving at about three times the speed, the fire density may be assumed four to eight times as high as in 1918. As in the fore-and-aft direction the increased speed of the target is without influence, and as the combat distances do not seem to be largely increased since 1918, more multiple hits may be expected. Photographs published of enemy aeroplanes which have been recently shot down, bear this argument out.

Through the large exit leak, a stream of petrol is forced in approximately the same direction as the bullet is travelling. Of course, it is by no means a sort of regular flow with high speed, but a very turbulent motion with spray and all kinds of the phenomena peculiar to a highly agitated waterfall.

With incendiary bullets, it is evident that they will not start a fire within the tank. Petrol or petrol fumes are not ignited by white phosphorus because no oxygen is present. Even with thermite, there is no surplus of oxygen which would permit an ignition or explosion to take place.

The phenomena happening after such a bullet has left the tank are less well established. It is assumed, and the science of ballistics seems to bear this out, that the incendiary bullet is incapable at any time of igniting the petrol. To do that the petrol spray would have to travel faster than the bullet in order to meet it, or, alternatively, an amount of petrol would have to adhere to the bullet itself. Hence it is concluded that the first bullet piercing a tank would not ignite it, and that it is always a subsequent incendiary bullet which causes the fire.

Yet it is an established fact, which has also been observed by Capitaine Harlé of the S.T.Aé., that ignition can be obtained well with a single bullet. One explanation may be that Mach's waves formed by the bullet, may make it possible for an amount of vaporised petrol to be carried along with the bullet into surrounding air, thus permitting an initiating explosion. Another possible explanation is that the squeezing out of molten phosphorus leaves in its trail particles of burning phosphorus or sufficiently hot gases, which can ignite the petrol spray following behind the bullet. How far sound waves occurring within the fluid petrol might be concerned, is not clear. In any case, their translatory motion is at least 30 per cent. faster than that of the bullet.

It has been found that the ignition never starts immediately behind the tank, but in its vicinity some distance away. Near to the tank, the mixture of petrol spray and air is far too rich for an explosion. This will only become possible farther away from the tank where the petrol spray has become so well mixed with air that an explosive mixture is present. In comparison with hydrogen, for instance, petrol has a fairly small explosive mixture range.

In actual air combat, it has been frequently observed that aeroplanes hit by incendiary bullets through the petrol tank, show at first a long trail of white smoke, before the fire becomes evident. This initial trail is petrol spray, and may be an evidence for the fact that the tank was pierced before ignition takes place, and that an amount of petrol escapes unignited. Alternatively, it may

be the petrol which has not become ignited because of lack of oxygen, while it was rushing out of the tank, the fire still being local.

The ignition is initiated by a local explosion which causes the neighbouring petrol spray to fire. This occurs in the same way as the initial ignition in the combustion chamber of a carburettor engine. After the initiating explosion, the flame quickly spreads back to the leak in the tank.

The phenomenon observed allows an explanation to be given of the somewhat startling failure of an armour-piercing incendiary bullet to ignite petrol tanks. This bullet is of the phosphorus type, the phosphorus only being released upon impact. The bullet is so constructed that it disintegrates on hitting a fluid. But as phosphorus is unable to cause an ignition within pure petrol, the use of this type of bullet was discontinued.

With detonating shells a different result can be expected. Shells which will detonate within a petrol tank or partly within it, are certainly likely to cause ignition.

PRINCIPLES OF PROTECTED TANKS.

The following conclusions affecting the design of tanks becomes obvious:—

(*a*) The entry hole made by a bullet is harmless, and no ignition will be connected with the entry.

(*b*) The sealing of a leak made by a bullet entering the tank is easy.

(*c*) The exit leak effected by a bullet which has passed the tank is large and presents difficulties in sealing.

(*d*) The pressure waves set up by the bullet within the petrol are the cause of the exit leak and will help to produce ignition.

(*e*) If the bullet can be made to stop inside the tank, no ignition may be expected.

(*f*) If the bullet can be separated from the petrol fluid while inside the tank, the exit leak will be small.

(*g*) If the bullet can be freed from any petrol at the moment it is leaving the tank, no ignition should take place.

(*h*) Incendiary bullets designed to disintegrate inside a petrol tank are unlikely to cause ignition.

A number of practical solutions were investigated.

The importance of the tank shape has already been mentioned. It proved to be practical to concentrate all petrol into one tank of compact size, in order to stop bullets inside. The fore-and-aft direction is considered the most dangerous one, as forming the easiest target. But it is obvious that hits piercing a corner can never be excluded. In addition, the requirement of a compact shape cannot always be complied with, for reasons inherent in aeroplane design. Nevertheless, the rule of massing the petrol should be adhered to as far as possible and should be given consideration in the first project lay-out. Incidentally, the weight of a tank protection will be the more reasonable, the larger the tank and the more compact its size.

The choice between metallic materials for tanks is not great. Brass behaves slightly different to tinned steel because of its elasticity, which will offer a higher resistance to the impact of pressure waves. But in both cases, the exit leaks will be approximately the same size and be rugged. Magnesium light alloys give large leaks but appear more preferable because the edges are not quite as deformed. The ignition of magnesium sheet as a primary cause has not been observed.

In order to restrict the pressure waves formed, experiments with baffle plates proved that the problem was to arrange these plates inside a tank so that all most likely hits were faced by them. A star-shaped arrangement seemed adequate, but made the construction heavy and complicated.

Another idea conceived was to place hollow containers or compartments inside the tank. These would be crushed under action of the pressure waves and thus relieve the impact. In crash tests the idea was found to be promising. There is no fundamental difference between a pressure wave set up by a crash and one set up by the impact of a bullet. The objection against the arrangement is, that the tank would have to be on the large size for these protective elements to have effect. Further, with a burst of bullets hitting, the protection is useless. The filling of the protective compartments with inert gases proved unsuccessful.

While the question of the most suitable elasticity of the tank cannot yet be definitely answered, too " soft " a tank system being apparently very likely to fail under action of resonance, the tank mounting has been proved to be of importance. The mounting should distribute the forces as universally as possible to the tank structure, and local accumulations of stresses, as with bracket mountings, should be carefully avoided.

FIG. 14.

Petrol tank arrangement in the undercarriage (Fokker C.I). The tank can neither be dropped not jettisoned.

The sealing of leaks in petrol tank walls was early considered. The means tested were materials which contracted the holes formed in them and/or which soaked in petrol under swelling. Such materials are natural rubber and certain kinds of gelatinous bodies, especially a gelatinous body known as " glue rubber," glycerine compounds with bichromates, etc.

While the sealing of the entry hole does not present difficulties, the rugged sheet edges of the exit leak press into the sealing compound, so keeping the leak open. Sealing compounds, generally, have no material strength.

With regard to swelling sealing compounds, it may be mentioned that the swelling time has been found to be of importance.

Tests with tanks having an outer cover of elastic rubber on top of the sealing layer were found to be less disappointing. It was thought that this rubber cover would also free the bullet from any adhering petrol. An additional outer wire netting resulted in improving sealing. It was claimed for the wire netting that it would cause bullets to disintegrate before their entry into the tank, but this claim is doubtful.

Up to this point the solution obtained for a relatively light self-sealing petrol tank was imperfect and unsatisfactory. Practically the same results were obtained with a large variety of sealing compounds and outer structures. As

long as the exit leak remained small, a protection against leaks was evident; with larger leaks and with bursts of bullets hitting the tank, no sealing was obtainable.

In addition, it was foreseen that higher rates of fire, ammunition of larger calibre and perhaps higher muzzle speeds would make the protection less effective. It seemed doubtful if an introduction of protected tanks was justified, in view of their increased weight, bulk and intricate construction.

This opinion may be surprising in view of the number of " crash and bullet-proof " safety tanks which have been tried since the great war. But those which proved to be fairly effective, though by no means giving a reliable protection against modern rifle-calibre incendiary ammunition, were found so heavy that they could not be recommended for the use in military aircraft of high performance.

On the other hand, it is remarkable how well founded some of these tank designs were. The design of Lieut. J. Imber, for instance, showed a clear insight into the mechanics of a bullet hit.

The experimental work of Captain Harlé showed that a fire never starts at the tank itself, and that it is splashed out petrol which brings the fire back to the tank.

The Daigre tank had a protection of a sealing gelatine compressed between the inner and the outer sheet metal shell of the container. The substitution of rubber and a wire mesh instead of the outer sheeting did not prove satisfactory. The tank was heavy and manufacturing difficulties with larger sizes have been reported.

The Lanser tank protection was built up with a felt cover on top of the inner sheeting. On top of the felt came several layers of elastic rubber, a wire net and an outer metal cover. With later models, the outer sheeting was omitted. The tank is very heavy.

The British Imber tank had a flexible inner structure formed by thin-walled aluminium tubes with a steel casing and an outer cover of vulcanised rubber (about $\frac{1}{4}$ in. thick) and reinforced corners. This tank was claimed to be bullet and crash-proof. A tank designed for a two-seater was dropped from 400 ft. height without showing a leak. Imber had noticed the difficulty in dealing with the rugged edges of the exit leak.

The S.E.M.A.P.E. tank of the Superflexit Company possesses several layers of rubber protection, leather and an iron wire mesh on top of a metal petrol container.

An official tank protection of the U.S. Air Corps has several covers of rubberised fabric, layers of pure rubber and of rubber compounds on the metal walls of the tank.

Interesting solutions were offered at the Safety Fuel Tank Competition of 1921-22 arranged by the Air Ministry. Three designs of crash-proof and bullet-protected tanks came into the final tests. The joint first winner were the Indiarubber, Guttapercha and Telegraph Works Co., Ltd., with a welded steel sheet tank having light gauge baffle plates, the whole inserted in a detachable rubber case, and the Imber Anti-Fire, Ltd., with a tank of a structure already mentioned. The third competitor, the late Commander F. L. M. Boothby, R.N., had submitted to the preliminary tests a very interesting, completely flexible tank consisting of a rubbered fabric bag containing the petrol, this bag being within an outer cover of rubbered fabric, while non-inflammable gas was introduced into the space between the two bags, under light pressure. The two fabric bags were enclosed in a three-plywood casing. The tank finally submitted had the fabric outer cover replaced by a plywood casing.[7]

The Boothby tank type seemed to be worth while, provided that the problem of rubbered fabric in petrol could be solved, as the lining with gold-beater's skin

[7] F. L. Boothby. Flight (The Aircraft Engineer), 27/1/1927, p. 7.

did not appear a satisfactory solution. Synthetic rubber, which has become available in recent years, might solve the problem.

With regard to self-sealing, however, the system is not convincing. In spite of the claim that the pressure waves set up by a bullet passing the petrol container would be rendered harmless by the flexibility and elasticity of the fabric walls, this tank will be obviously burst by a hit. The simple experiment of shooting through a pig's bladder filled with water will prove it. It cannot be assumed that the compressibility of the gas filling will prevent bursting, as the gas pressure will be immediately relieved, as soon as the bullet has pierced the outer wall.

Hence an arrangement must be incorporated to seal the burst wall parts immediately and to free the passing bullet from the petrol, if ignition is to be avoided. It is difficult to see how this can be done with such a fully flexible tank system.

One of the remarkable features of the Boothby tank was its extraordinary low weight of 0.55-0.66 lb. per gallon for the preliminary and of 1.13 lb./gal. for the final type. It seemed to indicate that a big sacrifice in weight was not necessary for tank protection, if new methods could be developed.

Crash Fires and Modern Solutions.

While the design of a bullet-protected tank was still unsatisfactory, it was decided to do away with all the complications and to incorporate unprotected tanks with a device permitting them to be dropped at any time and in any attitude of the aeroplane, especially in a spin. The content of a very small and armoured header tank would allow then the aeroplane to land safely.

Until recently, the bullet-protected or puncture-proof fuel tank was not considered worth while further consideration.

The frequent fires following even fairly minor landing mishaps with high speed machines, however, appear to have shown beyond doubt that a crash-proof tank was worth while developing, even if a certain amount of useful load would have to be sacrificed.

The investigation of certain aeroplane crashes in which fire had definitely started after the engine had parted under the impact from the airframe, seemed to confirm the view that many otherwise unexplained petrol fires, particularly those experienced with tanks located in a protected position, might have their origin in discharges of electricity.

It is a well established fact that petrol and similar fuels cause an electric potential while flowing through pipes.[8] The same phenomenon has caused, with hydrogen, numerous balloon and airship disasters, especially during the filling manipulations and, particularly, if sand or rust were present.

Experiments showed that even with such a small quantity of petrol as 0.2 litre which was being forced by compressed air through a nozzle, tensions of up to 1,200 volts could be obtained. A closer study showed that bursting tanks or pipes will produce large voltages if the petrol spray is being forced against a metallic wall, under partial vaporisation. Under these circumstances, it is quite easy to obtain a spark discharge which will cause an explosion of a petrol-air mixture.

From this, the obvious deduction was drawn that metallic fuel tanks would not safeguard against crash fires. Tests were carried out with the object of replacing metallic tanks by non-conducting materials.

Among prospective non-conducting materials for fuel tanks, synthetic rubber, fibre, plywood, cork compounds, concrete compounds and similar materials based upon silicates and synthetic resins came first under consideration. Besides the electric non-conductivity, the structural behaviour of the material under the impact

[8] The accident of Capt. Musiek, which occurred during jettisoning petrol while crossing the Pacific with a flying boat, might find its explanation in the same cause.

of fluid pressure waves needed attention. The type of fracture under such loading was considered essential.

Rubber, vulcanic fibre and cork compounds were not found practical, due to their mechanical properties. While no rugged protruding edges were formed, a wide system of deep cracks are generated, usually in all portions of the container, and this makes the tank shell likely to break down. Further, with hard rubber and fibre, fairly sharply edged, hard splinters of some length affect the outer protection and might render the tank ineffective.

Those materials which combined reasonably high elastic and impact strength properties with a low specific weight, which were easily shaped, and which were not so liable to extensive crack formation under impact appeared more suitable. An excellent composite material, which was petrol-resisting without needing a further treatment, was found in compressed laminated plastics, such as paper sheets or fabric treated and compressed with phenol formaldehydes.[9] It also could be expected that composite wood plastics, like bakelite, glued plywood or " improved " wood, such as commonly used in the modern aeroplane manufacture, would be suitable for the construction of petrol containers.[10] Plastics made with insertions of fine wire meshes are stronger but seem unsuitable for tank shells.

An advantage with this development is that the tank cannot only be made with a very reasonable weight, compared with welded magnesium alloy tanks, but can also be made in any desired shape by pressing and can, further, incorporate from the beginning all stiffeners, diaphragm frames, bulkheads, tank fittings, etc., required.

The serious difficulty is the petrol-tight joining of the shell parts. Riveting alone will not be sufficient for a prolonged use, and a suitable kind of cementing or glueing the shell portions and accessories is necessary. Generally, aminoplastics are to-day in use for that purpose.

Another point is the proper joining of fittings to such tank shells. Theoretically, it would be highly desirable to have them made from plastics as well.

Tank shells of this kind will form the basis of a modern fuel tank protection. If baffle plates are fitted, and they ought to be, except for very small tanks, they will have to be of non-metallic materials as well. How far the stiffness of a tank shell should go, is still a matter of argument. As already mentioned, the tank mounting has a lot to do with it.

The outer protection comprises covers for keeping the fluid in case of a shell rupture (petrol-tight strong fabric, treated skin, parchment, etc.), a fairly thick layer of a satisfactory sealing compound, and an elastic compressing and sealing bandage (commonly, highly elastic vulcanised rubber, especially of a quality made from thin layers of dipped " patent " rubber). The compressing cover is necessary because of the low mechanical strength of the sealing compound; it will also help to separate a bullet from the petrol.

This whole structure may either be enclosed in a wire net of a large mesh which is electrically connected with other metal aircraft parts, or, preferably, in a non-metallic outer casing (plywood, for instance) which will protect the rubber components from deterioration.

As to the mounting, two essential points will have to be observed. For a protected tank, a mounting in brackets is absolutely unsatisfactory. The tank should be mounted either in a cradle or, better, in straps which permit an elastic mounting without stressing the tank. Wide straps are to be given the preference, of course.

[9] In this connection it seems fair to mention that two Austrian chemists, L. Wolf and M. Stein, secured as far back as July, 1918, a patent for the use of laminated compressed cellulose plastics based on formaldehydes for aeroplane petrol tanks (German Patent No. 321,849).

[10] Recent references in the American technical literature (see " The Journal of the Aeronautical Sciences," January, 1937) confirm this view.

Another point is that the tank must be so designed and mounted that overflowing petrol can neither reach the protective cover nor be collected nor soaked in by neighbouring parts of the tank. A piece of felt in the holding straps of a fuel tank which has become soaked with petrol will render the most elaborate tank protection useless.

It still seems a somewhat controversial matter if it is preferable to provide for ventilation of the space around a petrol tank or not. As long as safe precautions will exclude the formation of petrol fumes in the tank compartment, it will be better to ventilate it thoroughly during flight. If petrol fumes can normally be expected, it is safer to keep the compartment airtight so that the fumes cannot penetrate into neighbouring parts of the structure, but will remain of a non-explosive nature, due to lack of oxygen.

Another point to be observed with protected petrol tanks is their interchangeability. With a well protected tank, a hit is neither very obvious nor easy to repair. A hit tank should under no circumstances be used again, before a thorough repair has been effected. The protected tank should therefore be easily interchangeable.

A petrol tank recently discovered in a captured Heinkel bomber seems to correspond fairly closely with the recommendations outlined above.

After all, it may still be argued that a protected petrol tank will not give absolute protection against tank fires. It may be mentioned that the light fuel oils used in the compression ignition engine can be quite as easily ignited with modern incendiary ammunition as petrol.

Probably, the aeroplane designer will be sceptical with regard to the introduction of non-metallic petrol tanks, and he will most certainly object to fuel tanks which not only weigh about three times as much as a modern welded magnesium alloy tank (see Table I), but are even more bulky.

A serious point against the introduction of protected tanks is without doubt the tendency to incorporate the fuel tank directly in the structure of the aeroplane, *i.e.*, to make use of the modern stressed-skin construction for the immediate storage of the fuel. That this way saves structural weight and adds to performance has been shown by Seversky. It is not easy to foresee how such inherent petrol containers can be effectively protected.

It is, of course, purely a matter for the military authorities to decide if and in which specific cases, the protection of petrol tanks is considered a fighting necessity.

TABLE I.

AVERAGE UNIT WEIGHTS OF PETROL TANKS.

(About 50 gal. capacity.)

Steel plate tanks (obsolete)	1.20	lb./gal.
Brass tanks (obsolete)	1.20	,,
,, ,, seat type, maximum value	1.46	,,
Aluminium tank, mounted in brackets	0.75	,,
,, ,, mounted in straps	0.60	,,
Magnesium alloy tank, bracket mounted	0.48	,,
,, ,, welded and strap mounted ...	0.35	,,
Welded magnesium alloy tank (experimental)	0.20	,,
Self-sealing brass tank (1918)...	2.20	,,
Indiarubber Co. protected tank (1922)	1.90	,,
Imber protected tank (1922)	1.70	,,
Boothby flexible protected tank (1922)	1.05	,,
,, ,, ,, ,, (preliminary model) ...	c.58	,,
U.S.A. leak-proof tank (1925)	1.92	,,
U.S.A. crash-proof tank (1925)	1.50	,,

REVIEWS.

PRINCIPLES AND PRACTICE OF AVIATION MEDICINE.

By Harry G. Armstrong, B.S., M.D. Pp. 496. £1 16s. 0d. London: Bailliere, Tindall and Cox.

This is probably the most important work on aviation medicine yet produced. There are 27 chapters dealing with aviation medicine in every aspect. Some of these—the physiological and pathological effects of flight—very exhaustively; others, such as preventive and industrial medicine, more slightly.

It is not an easy book for the reviewer, who should be not only a physician and surgeon, but a specialist in many of the branches of his art—an ophthalmologist, physiologist, psychologist, biochemist—and also a mechanical engineer, with a specialised knowledge of many technical instruments. All are dealt with in this book in one or other relation to aviation.

As would be expected the selection of the pilot and the tests he must undergo are dealt with very fully, and also the effects on the various organs and functions necessitating orientation in its broadest and narrowest sense.

The effect of speed and particularly that of acceleration is well described, and also the influence of successive G's on the cardiovascular system. The author has not given an explanation of the phenomenon of "blacking out," about which ophthalmologists are not yet agreed.

One may be too optimistic to expect very new ideas and knowledge to be presented in this book. The effect of diet value where oxygen deprivation is concerned is probably too new to be dealt with, but one would expect a little more concerning the transmission of disease by aircraft.

The references are fairly extensive, but the book index is poor. For such an important book the paper is quite second rate.

Many ideas will be revised as a result of the intensive flying under war conditions; even the difficult G strain may be combated, but this book will for some time be regarded as the standard book of reference.

"MORE CHARLTON."

By Air Commodore L. E. O. Charlton, D.S.O. Longmans, Green and Co. 12/-.

"Portraits of the Artist" never look really natural, and this autobiography in the third person is marred by a similar self-consciousness. Readers not fortified by the knowledge that "War-over-England" Charlton can write forcibly and well, will probably wilt under the heavy facetiousness of the opening pages, and lay the book aside unread. Anyone arriving at page 50 will be encouraged by a diverting account of Charlton's experiences as official British representative at the ceremonies in honour of a fallen Mexican airman. The taste of this is questionable, but its style is attractive.

From this point onwards, the disconnected reminiscences might well be entitled: "Private life of an Elderly Buffer," until at last on page 257 the real Charlton emerges in a caustic passage on air raids:—

"What is the use of cowering underground in a state of claustrophobic terror when the wreckage of all that civilisation means is accumulating overhead? . . . It is a hard saying, but the lives of civilians are cheaper while a war is on than at any other time. . . . Safety, if there be such, rests in the reciprocity of warfare from the air, and the tit-for-tatness of its method."

This is the Charlton of whom we would like to have more.

LORDS OF THE AIR.

Harry Harper, R.T.S. Lutterworth Press, London. 8s. 6d. net.

Harry Harper is one of the pioneer aeronautical journalists. He has followed and reported aviation from the days of its romantic, fiery pioneering enthusiasm to the days when nearly all the romance has been bombed out of it. He has known the air giants of old, Rolls, Cody, Grace, Grahame White, Hucks, R. T. Gates, Hawker, Blèriot, Latham, Santos Dumont, to name only a few. He was present at the start of Blèriot's flight across the Channel, at the first Rheims meeting, and the London-Manchester race between Paulhan and Grahame White, the three great early classics of aviation.

His personal contacts, his vivid descriptions, and his own enthusiasm for aviation, makes this book one of high interest. It is only possible here to quote a little. Here is a story of Sir A. V. Roe which may not be well known.

" A.V.," in his early days, spent a great deal of time launching paper gliders from an upper window of his house. The neighbouring building happened to be a lunatic asylum. When the doctor came to visit a certain patient, the latter took him to the window of his room and pointed across to the house where A. V. Roe was living.

" Ours isn't the only mental hospital," he observed sagely. " There's another one over there."

" But that isn't a mental hospital," the doctor told him.

" Well, if it isn't," insisted the patient, " there's a lunatic living there, all the same. He just throws bits of paper out of the window all day long. Then he hurries downstairs and picks them up and puts them in a basket. And then he just throws them all out of the window again."

Out of his " madness," A.V. became the designer of the most famous aeroplane of the 1914-18 war, the Avro 504.

Of Samuel Franklin Cody, the author very rightly remarks, " If I were asked to name the most striking of all figures in early aviation, I think I should plump for this astonishing Cody." And many who knew Cody would agree with that verdict.

It was Moore-Brabazon, holder of No. 1 pilot's certificate, who killed the old saying, " Pigs might fly," in those early days of flight. A squealing indignant little porker was duly carried up aloft to alter the saying to " Pigs can fly."

From those early happy pioneer days to the modern fierce competition of nations, as to which can drop the maximum number of bombs in the minimum of time, seems a long air road. Harry Harper has traversed the whole length of this road, a road so packed with interesting things to see, so full of interesting people, and so full of romance, laughter, tragedy, and high endeavour, that it would take a dozen books to give it full justice. Here the high lights are sketched in to give one a wish for more.

CORRESPONDENCE.

Sir,—May I supplement the historical facts mentioned with regard to tandem and co-axial counter-rotating airscrews as given by Mr. H. M. McCoy in his recent paper (June issue of the " Journal," p. 483-484).

1. Tandem Airscrew-Engine Arrangement.

The first known arrangement of this kind was the Short S.37 " Double Twin " biplane with two 50 h.p. rotary engines, the pilot being sandwiched between them. This arrangement, characterised by a nacelle with one or two seats and engines at both ends, has since fairly often been copied, notwithstanding the obvious disadvantages as, for instance, in 1915 by Fokker with his experimental G.1 type, a twin-fuselage construction, by Siemens in 1916 with an experimental single-seater fighter, and in more recent times by Bellanca with a long-distance aeroplane of 1929.

It is, incidentally, interesting to note that Fokker returned to this arrangement in 1938 with his latest single-seater fighter.

The same arrangement has also been incorporated in the Palmer biplane two-seater of 1917 (1).

The non-central tandem arrangement seems to have at first been realised by I. Sikorsky in his first multi-engined aeroplane " The Grand " in May, 1913, and was subsequently given up as unsatisfactory. But in 1916, propeller tests made by C. Dornier proved so successful that the tandem arrangement was incorporated in nearly all flying boats, beginning with the type Rs. IIa (in replacement of the previous gear drive which was found to be heavy and unreliable). The tandem arrangement is also found in most German four and five-engined aeroplanes of the war period since about 1915-16, especially in the Staaken type of Prof. Baumann.

In recent times, an original tandem arrangement is shown by a Piaggio four-engined trans-Atlantic landplane of 1935. This is a monoplane with two tractor airscrews in front of the wing and two pusher airscrews behind it, while the engines are mounted directly at the wing.

2. Co-axial Oppositely Rotating Airscrews Placed Immediately One Behind the Other.

This feature was tried in 1903 by the ingenious Levavasseur. His first monoplane, an unsuccessfully tested affair, had two four-bladed tandem airscrews (2).

In 1909 the late Ferber, a close friend of Levavasseur, incorporated two co-axial tractor airscrews in a biplane equipped with a 24 h.p. engine, the pilot sitting between engine and the airscrews. The latter were expected to turn with 600 r.p.m., having a diameter of 2.50 m. and a pitch of 2 m. (3, 4).

In a Howard Wright biplane, pusher airscrews were used, driven by a 50 h.p. engine with the use of a differential gear attached to the stationary engine. With this arrangement, the front airscrew had the greater diameter (5).

In the autumn of 1909, a Faure-Deperdussin " tail-first " monoplane was exhibited in a Paris store which had two tandem pusher airscrews driven by a 65 h.p. engine mounted in front of the pilot (6).

In 1910, the Pigott biplane had two pusher airscrews of this nature, with a planetary gear and a chain drive (7). A Schindler-Brzesky with an oppositely rotating engine and counter-rotating airscrews was tested near Vienna (8). The Bernh. Escher machine factory at Chemnitz designed a special " reaction-free "

rotary engine for the drive of co-axial counter-rotating airscrews. Four airscrews of this arrangement, but driven by a stationary engine, were incorporated in the Joachimczyk tandem monoplane constructed near Berlin.

None of these aeroplanes had any success.

The first successful flight with tandem airscrews was made by the late Hellmuth Hirth in February, 1912, in Johannisthal, near Berlin. This was with a Loutzkoy monoplane constructed by the Rumpler works and very similar to an enlarged Etrich "Taube," but having two 100 h.p. Argus engines driving two tandem tractor airscrews which were, however, at first of the same rotational sense. Hirth found the plane very easy to fly, and subsequent tests proved quite successful (9). The drive was protected by a patent (10). If I remember rightly, Hirth told me that, later on, tests with oppositely rotating airscrews were discontinued because of the lack of interest the authorities displayed in this early twin-engined affair. Anyhow, Hellmuth Hirth can be claimed to be the first man who has flown with a dual-rotation airscrew system on a conventional aeroplane. The exact date was February 19th, 1912.

In 1917, the Italian "B.T." single-seater design showed an oppositely rotating pair of tandem pusher airscrews at the stern of a fuselage of a normal biplane. The airscrews were driven by a bi-rotational water-cooled rotary engine, probably the only water-cooled rotary ever attempted (11).

In recent years, several engines have been developed for the drive of counter-rotating tandem airscrews. In about 1929, the double Fiat racing engine group consisting of two twelve-cylinder engines coupled together was evolved and later successfully employed. In 1935, the Lorraine Petrel "H.A.R.S." was designed for twin airscrews and installed in the Koolhoven F.K. 55 fighter of 1936. In 1937, a French Régnier twelve-cylinder engine for light fighters was equipped with a synchronised differential gear for the drive of two co-axial airscrews.

As with so many aeronautical "innovations," a study of the technical development shows that the evolution is often nothing more than the grasping of old ideas at the appropriate moment.

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(1) "Aircraft," June, 1917, p. 108.
(2) Ferber, Pas á Pas, Paris, 1906, p. 40.
(3) Hoernes, Buch des Fluges, Vol. 2, p. 97.
(4) R. de Gaston, Les Aéroplanes de 1910, Paris, 1910.
(5) Flight, 1909, p. 176.
(6) "Flugsport," 1909, p. 752.
(7) Flight, 1910, p. 383-386.
(8) "Flugsport," 1910, p. 740.
(9) "Flugsport," 1912, p. 189.
(10) German Patent No. 263,059; "Flugsport," 1913, p. 730.
(11) Atti Del Primo Congresso Internazionale Del Motore a Scoppio, 1927, p. 184-192.

I am, Sir, yours faithfully,

A. R. WEYL (A.F.R.Ae.S.).

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